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Discrimination of the lower and the upper Nimar Sandstone (Upper Cretaceous Bagh Group), Madhya Pradesh, India based on lithofacies and ichnofauna

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Integrated lithofacies analysis and systematic trace fossil analysis has been done of the Nimar Sandstone of the Bagh Group, Madhya Pradesh, India in three sections viz. the Bagh Cave section, the Naingaon section, and the Hathni River section. The thickness of the Nimar Sandstone varies from 10m to 30m in the studied sections. Based on the lithofacies and trace fossil characters, the Nimar Sandstone can be further subdivided into ferruginous sandstone in the lower part as the lower Nimar Sandstone (lNS) and calcareous sandstone as the upper Nimar Sandstone (uNS) in the upper part. The lNS is characterized by eight following lithofacies (i) cross-bedded gravely 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, (viii) bioturbated mottled mudstone having trace fossil of *Arenicolites, Diplocraterion, Laevicyclus, Ophiomorpha, Skolithos,* and *Thalassinoides* ichnogenera. The uNS includes four lithofacies (i) sandstone with the tidal bundle, (ii) small-scale cross-bedded calcareous sandstone, (iii) interbedded calcareous sandstone-siltstone-mudstone, (iv) fossiliferous calcareous sandstone characterized by ichnogenera of *Arenicolites, Asterosoma, Dactylophycus, Skolithos, Taenidium, Teichichnus, Thalassinoides,* and *Zoophycos*. Lithofacies association, different sedimentological attributes, and ichnological data indicate a complete evaluation of the river-dominated estuary to tide-dominated estuary from the base to the top during the deposition of the lower Nimar Sandstone. The upper Nimar Sandstone was deposited under subtidal inner neritic conditions where carbonate could precipitate. The whole succession of the Nimar Sandstone represents a Transgressive Systems Tract (TST) deposit of a 3rd sea-level cycle.

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INTRODUCTION

The Bagh Group, popularly known as the Bagh Beds of the Upper Cretaceous age, is exposed along the Narmada valley at various places in western-central India. Isolated exposures of the Bagh Group are found in the vicinity of the Narmada Valley extending from Barwaha in Khargone district (M.P.) in the east to about 300 km away Kawant, Baroda (Gujarat) in the west (Kennedy *et al.,* 2003). In most of the areas, the Bagh Group of rocks rest along an angular unconformity above the Precambrian basement rocks and in turn are overlain by the Deccan Trap Volcanics. The Bagh Group of rocks, characterized by thick siliciclastic and calcareous sediments, were deposited during the Late Cretaceous global sea-level rise in a shallow epi-continental sea or an embayment that invaded the western and central parts of India from the west along the Narmada valley (Singh, 1981; Singh and Srivastava, 1981; Saha *et al.,* 2010; Saha, 2013; Jaitly and Ajane, 2013; Bhattacharya *et al.,* 2020). Earlier, Sahni (1983) also proposed a 'Trans Deccan Straits' which followed the Narmada as well as the Godavari rift zones. Recently, Kumari *et al.* (2020) and Keller *et al.* (2021) reiterated two marine seaways that might have joined through the Narmada-Tapti and Krishna-Godavari rifts forming a Trans-India Seaway which was formerly proposed by Sahni (1983).

The Bagh Group comprises three formations (Table 1), which in ascending order are: (i) Nimar Sandstone, (ii) Nodular Limestone, and (iii) Coralline Limestone (Tripathi, 2006; Jaitly and Ajane, 2013). The Bagh Group has been intensively investigated for stratigraphy and palaeontology for more than 150 years (Blandford, 1869; Rode and Chiplonkar, 1935; Roy Chowdhury and Sastri, 1962; Dassarma and Sinha, 1975; Chiplonkar *et al.,* 1977; Ganguly and Bardhan, 1993; Acharyya and Lahiri, 1991; Gangopadhyay and Bardhan, 2000; Bardhan *et al.,* 2002; Kennedy *et al.,* 2003; Khosla *et al.,* 2003; Jaitly and Ajane, 2013; Kumar *et al.,* 2018). The ichnofauna of the Bagh Group has been studied by Chiplonkar and Badve (1969), Singh and Dayal 1(979), Verma (1971), Chiplonkar and Ghare (1975), Badve and

Table 1. Lithostratigraphy of the Bagh Group (modified after Jaitly and Ajane, 2013).

Group	Formation	Member	Age	Dominant / characteristic Lithology
	Lameta Group and Deccan Traps			
Bagh	Coralline Limestone		Coniacian	Reddish brown to yellow coloured bryozoan limestone
	Nodular Limestone	Chirakhan	Turonian	Bioturbated limestone and marl with calcareous nodules
		Karondia		Nodular limestone with ample marine invertebrate fossils
	Nimar Sandstone	upper Nimar Sandstone (uNS)	Cenomanian	Whitish to cream coloured, well sorted, medium to fine grained calcareous sandstone, with variety of trace fossils, fossils and sedimentary structures of marine origin
		lower Nimar Sandstone (lNS)	Pre-Cenomanian ?	Red to brick red coloured, ferruginous coarse to medium grained, large scale cross bedded sandstone with conglomerate unit at the base and intermittent bioturbated mudstone units
		~~ Unconformity ~~~~~~~~~~~~~~~~~		
		Crystalline rocks		

Ghare (1980), Badve (1987), Mohabey (1996), Sanganwar and Kundal (1997), Kundal and Sanganwar (1998, 2000), Nayak (2000) and Khosla *et al.,* (2003) to understand the palaeoenvironmental condition of the Bagh Group.

Bose (1884) subdivided the Nimar Sandstone into the *Lower Member* consisting mainly of conglomerate, sandstone, and carbonaceous clay, and the *Upper Member* characterized by calcareous sandstone with marine fossils. According to Singh and Ghosh (1977), Singh and Dayal (1979), and Tripathi (2006), the lower part of the Nimar Sandstone represents a fresh water environment, whereas the upper calcareous sandstone is a product of a shallow marine setting. Later, Bose and Das (1986) based on lithofacies analysis suggested that the lower part of the Nimar Sandstone indicates a transgressive storm and a fair-weather wave-dominated shelf sequence. Recently, Bhattacharya *et al.* (2020) interpreted the lower part to denote a fluvial setting, whereas the upper part of the sandstone is a transgressive fluvio-marine estuarine deposit.

In the present study, based on the sedimentological and ichnological attributes, the Nimar Sandstone has been subdivided into the lower Nimar Sandstone (lNS) and the upper Nimar Sandstone (uNS). Outcrop-based lithofacies analysis coupled with trace fossil systematics have been attained mainly from the Nimar Sandstone of the Bagh Group located in and around the Bagh town, which is also the type locality for the Bagh Group. The purpose of the present study is to firmly discriminate the lNS from the uNS whose status is still dubious and has been loosely used in the literature. Moreover, the proposed depositional environments of the Nimar Sandstone are highly controversial ranging from fluvial to marine and estuarine. Our study is based on minute field observations of the trace fossils along with substrate characteristics. For the present study, the generic level identifications of individual trace fossils have been carried out in the field and supplemented with photographs in the lab. Because of the small to large size of the trace fossils that are embedded either in the friable sandstone of the lNS or the chertified and calcareous lithology of the uNS, could not be extracted from the outcrop and carried to the lab.

GEOLOGICAL SETTING

The Cretaceous infra-trappean sediments of the Narmada valley, western and central India were deposited in an intra-cratonic basin over the Precambrian basement (Biswas, 1987; Sridhar and Tripathi, 2001; Tripathi, 2006). Within this linear trough-like valley, a thin sedimentary sequence developed during the Cretaceous time is referred to as the Lameta Formation in the central part and the Bagh Group in the western part of India respectively (Shukla and Srivastava, 2008; Saha *et al.*, 2010; Srivastava *et al.*, 2015; Bhattacharya *et al.*, 2020**)**. Both, the Lameta Formation and the Bagh Group occur as isolated outcrops all along the Narmada valley (Fig. 1).

Based on ammonite and inoceramid evidence, Kennedy *et al.* (2003) dated the Bagh Group as Late Turonian to Coniacian. Based on lateral facies variation, Tripathi (1995) subdivided the sedimentary sequence of the lower Narmada valley, western India into several members. Jaitly and Ajane (2013) classified the Bagh Group into the Nimar Sandstone, overlain by the Nodular Limestone and the Coralline Limestone which range in age from Cenomanian, Turonian, and Coniacian respectively (Table 1). Later, Ruidas *et al.* (2018) renamed the Coralline Limestone as the Bryozoan Limestone.

The present work incorporates systematically measured sections with detailed sedimentology and studies of the ichnofossil of the Nimar Sandstone in the Bagh Cave, Naingaon, and Hathni River sections (Figs.1 and 2). At the Bagh Cave and the Naingaon sections, the Nimar Sandstone measuring 25m to 30 m is ferruginous, gravelly at the base with fining upward character. In the upper part, the Nimar Sandstone becomes calcareous sandstone (Fig. 2). The rocks gently dip at an angle of 6^0 to 8^0 towards S20^0 W. The multistoried Nimar Sandstone is vertically stacked having erosional contacts at the base of each story and running parallel along the strike forming sheets or tabular and locally lensoidal geometries (Fig. 3). The famous Bagh Caves are excavated in the lower Nimar Sandstone (lNS) using the strike face of the rocks.

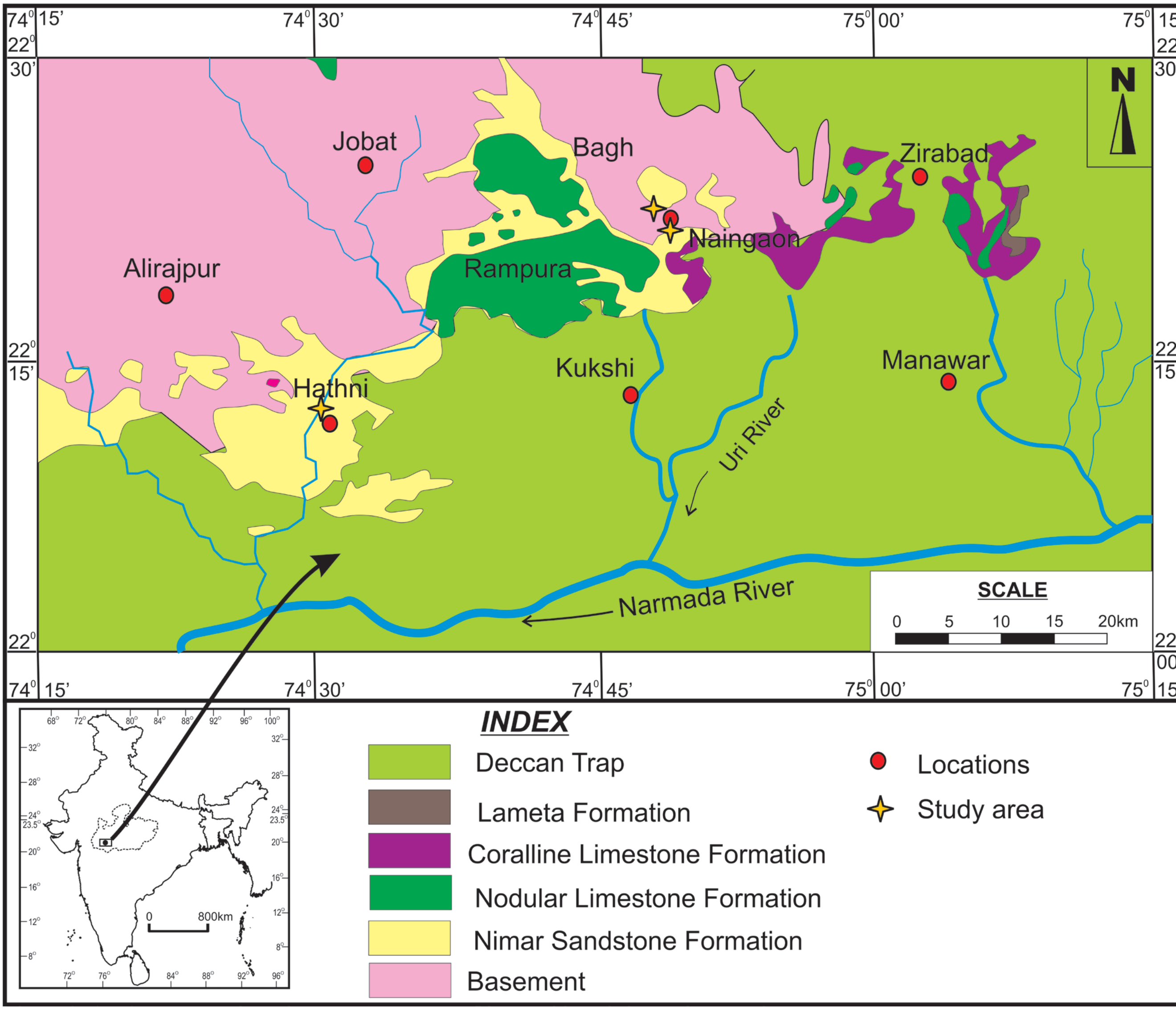

Fig. 1. Geological map showing the location of study area modified after Jaitly and Ajane (2013).

The Hathni River Section, situated 25 to 30 km west of Kukshi town towards the Alirajpur road, is located near Nagpur Fata (Fig. 1). The section is well exposed on the left bank of the Hathni River and extends laterally for 700 m to 800 m. In this section, the gravelly red coloured sandstone, the lower part of the lNS, is not developed and the sequence is composed of 3 to 4 upward fining sandstone complexes. The measured thickness of Nimar Sandstone at Hathni River section is ~10 m (Fig. 2); it is overlain by Nodular Limestone and bioclastic Coralline Limestone (Table1).

SEDIMENTOLOGY

The Nimar Sandstone is buff red to yellow in colour mainly because of the ferruginous matrix. At the base, it is conglomeratic and is made up of subrounded to rounded pebbles embedded within coarse-grained sandstone. It shows overall fining upward character represented by 1 to 3 m thick inter-fingering lensoidal sand bodies, sometimes separated by laterally persistent brick red coloured burrowed mudstone (Figs. 3, 4). Gradually, in the upper part, the Nimar Sandstone becomes calcareous, which is relatively fine-grained with a variety of trace fossils. The upper calcareous sandstone bodies are relatively hard and compact, individual beds are thinner and separated by fine-grained sandstone and mudstone alternation or cycles and lack thick mudstone units (Fig. 5). Based on lithological character, the Nimar Sandstone can be divided into ferruginous sandstone as the lower Nimar Sandstone (lNS) and calcareous sandstone as the upper Nimar Sandstone (uNS) (Figs. 2 and 3) The characteristic sedimentological attributes of the lower Nimar Sandstone and the upper Nimar Sandstone are described in detail.

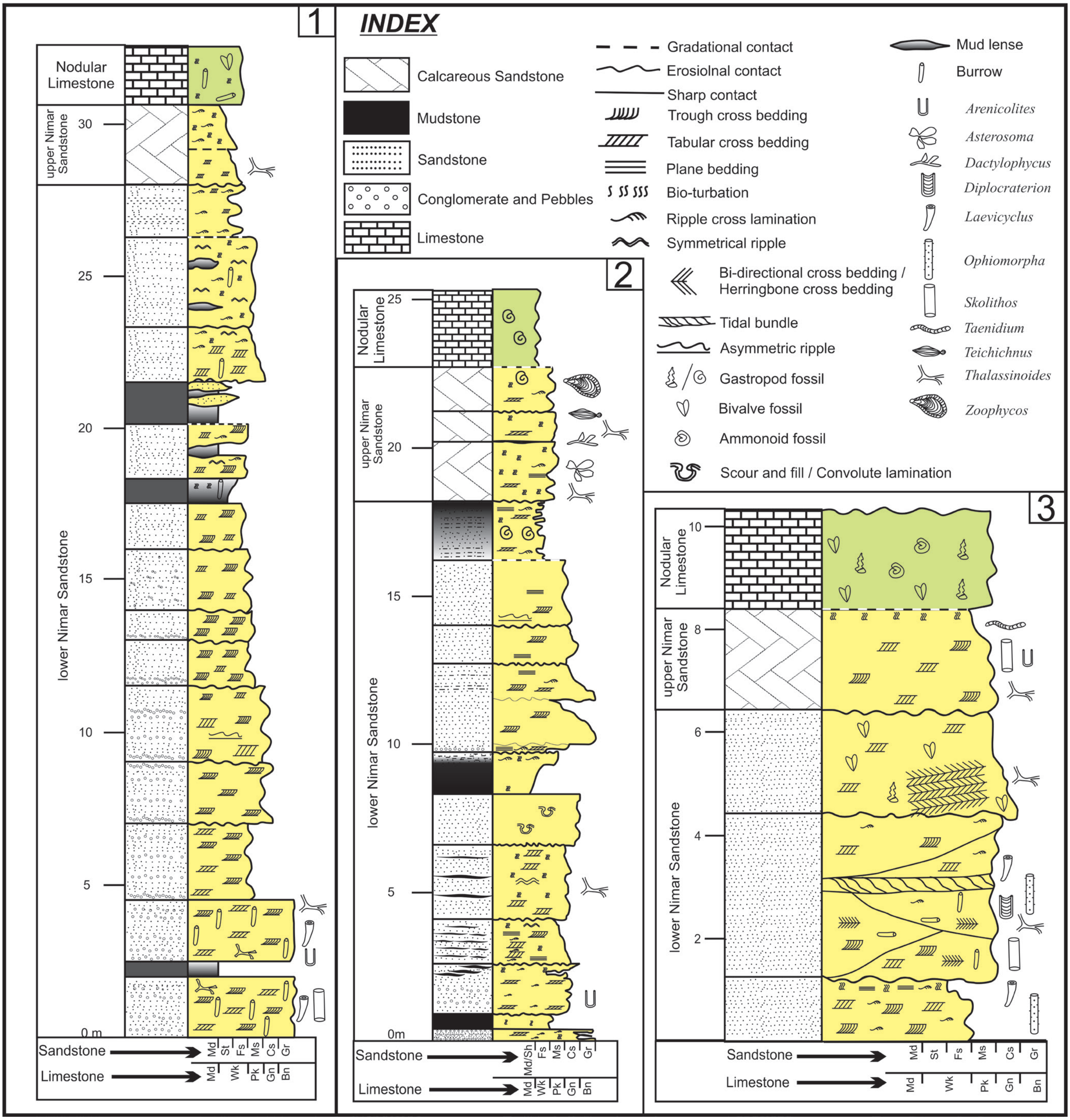

Fig. 2. Litholog showing major lihology and distribution of primary sedimentary structures and trace fossils of (1) Naingaon Section; (2) Bagh Cave Section and (3) Hathni River Section.

lower Nimar Sandstone (lNS)

The thickness of the lNS ranges from 18 m in the Bagh Cave section to 25 m in the Naingaon section and 7 m in the Hathni River section (Fig. 2). The lowermost part of the Nimar Sandstone is characterized by coarse-grained ferruginous gravelly sandstone having large scale cross-bedded (50 cm to 100 cm or more) (Figs. 4.1 and 4.2). The size of the gravel varies from mm to a few cm. Important features are intense palaeocurrent reversals (Fig. 4.2), herringbone cross-beds (Fig. 4.3), interference ripple marks (Fig. 4.4), trace fossils with paired burrow openings, syn-sedimentary deformation structure (Fig. 7.1). These sand bodies trend roughly in the NE-SW direction. The well persistent gravelly or conglomeratic sandstone bodies gradually become lensoidal in character at the middle part with the decrease in the grain size to medium-grained. At this level, the sand bodies are ferrugenised buff red colour, medium to fine-grained, well-sorted, devoid of gravels having individual sand body thickness of about 2.5 m, and are well exposed at the Bagh

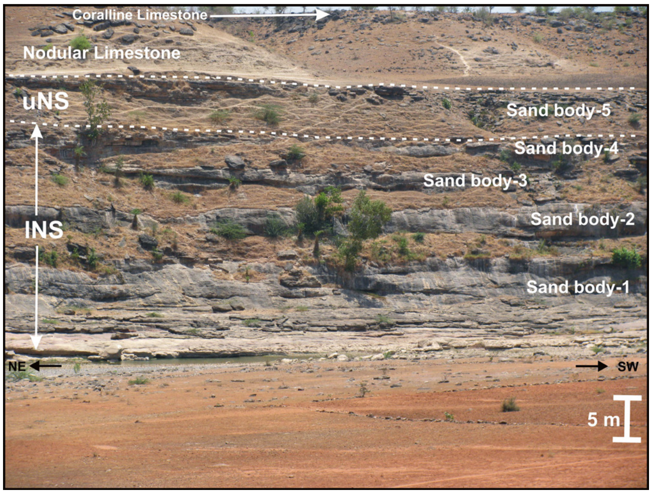

Fig. 3. Field photograph showing multi-storied nature of the Nimar Sandstone showing gradational contact between the lower Nimar Sandstone (lNS) and the upper Nimar Sandstone (uNS) overlain by Nodular Limestone and top is covered by Coralline Limestone exposed near Naingaon along Baghini River; scale bar = 5 m.

Cave section (Fig. 2). The lensoidal sand bodies show lateral shifting (LA element) and amalgamating character (Figs. 5.3 and 5.4). This sand body is made up of at least three shoaling bar complexes, which are vertically staged and laterally shifting (LA element). A single shoaling bar event is 70 to 80 cm thick and is made up of 18 to 25 cm thick lensoidal planer cross-bed set (Figs. 5.3 and, 5.4). The individual lensoidal sand bodies are characterized by the basal erosional surface at the center; whereas at the margin, it is either sharp or amalgamated and cross-bedded. The cross-bed has sharp contacts and is made up of migrating 20 to 30 cm thick 2-D ripples having a wavelength of about 2 m. Foresets of cross-beds are rippled with a prominent reactivation surface (Fig. 5.4). Locally, these cross bed sets are separated by 2 to 3 cm thick lenticular to flaser-bedded muddy horizons (Fig. 5.2). Mottling present within the cross-beds and bar surfaces is highly burrowed. Grain size and the sedimentary structures vary within the sand bodies both vertically and laterally. The different identifiable lithofacies in lower Nimar Sandstone are: (i) Cross-bedded gravely 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 (Fig. 5.1), (vii) Gravelly mudstone and (viii) Bio-turbated mottled mudstone lithofacies (Figs. 4 and 5). A prominent and laterally persistent horizon of the interbedded sandstone-siltstone-mudstone lithofacies gradationally caps the lNS and is overlain by the uNS along a sharp contact.

upper Nimar Sandstone (uNS)

The thickness of the uNS varies from 2 to 5 m; 5 m in the Bagh Cave section, 3 m in the Naingaon section and 2 m in the Hathni River section (Fig. 2). Thickly developed sandstone bodies are composed of 3 to 4 vertically stacked stories. The calcareous sandstone bodies are relatively hard, compact, partly chertified, and feebly ferruginised in

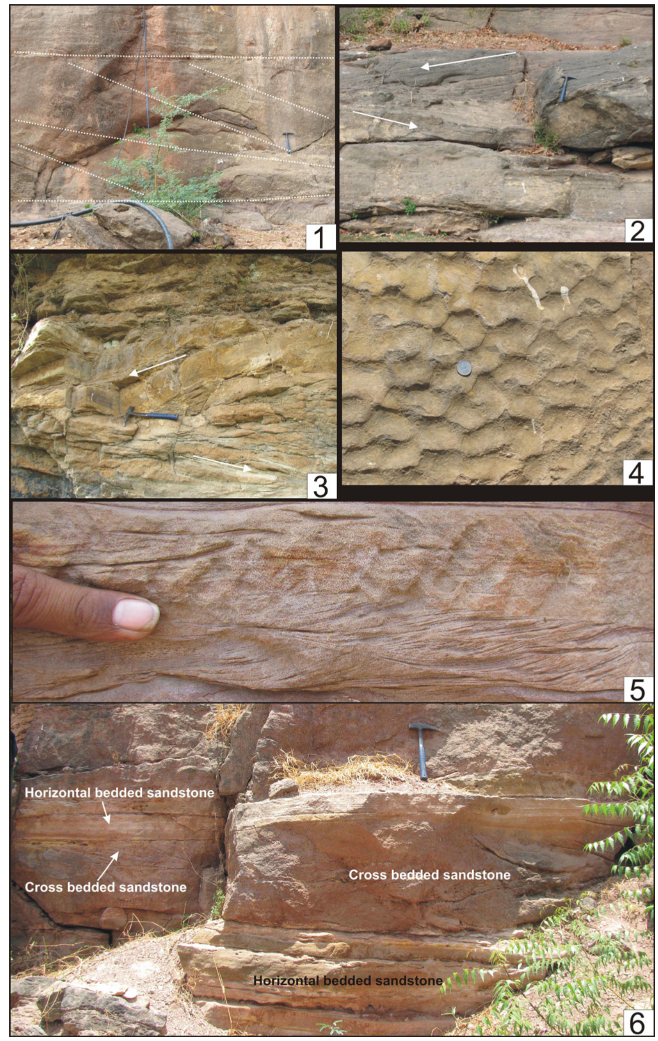

Fig. 4. Field photographs showing different sedimentological and lithofacies characters of the lower Nimar Sandstone (lNS); (1) Cross bedded gravelly sandstone lithofacies showing large scale cross bedding within the lNS at Naingaon section; length of the hammer is 32 cm. (2) Large scale planar cross bed within the cross bedded gravelly sandstone lithofacies (white coloured arrow shows palaeocurrent reversal) of the lNS at Naingaon section; length of the hammer is 32 cm. (3) Herringbone cross-bedded sandstone lithofacies showing bipolar palaeocurrent (marked by white arrow) and mud drapes on the foresets of the cross-bedding within the lNS at Hathni River section. (4) Interference ripples within the cross-bedded gravelly sandstone lithofacies of lNS at Naingaon section; diameter of the coin is 2 cm. (5) Ripple drift cross-laminated lithofacies showing drifting nature of individual bundles separated by reactivation surfaces; finger is for reference scale. (6) Planar cross-bedded sandstone lithofacies is bounded by horizontally bedded sandstone lithofacies as topset and bottom set at Bagh Cave section, note the well-defined reactivation surfaces implying episodic bedform movement under tidal action; the length of the hammer is 32 cm.

the upper part. Beds constituting the individual stories are thinner (average 20 cm thick) and separated by a few cm to dcm thick fine-grained sandstone and mudstone alternations forming cycles; but lacking in the thicker gravelly mudstone units as encountered in the lNS (Fig. 6). The calcareous sandstone, well persistent throughout the study area, is internally whitish to cream coloured, sporadically on the surface it also gives yellow to pink colour (Fig. 6). Locally, the whole unit is represented by 3 to 4 vertically stacked

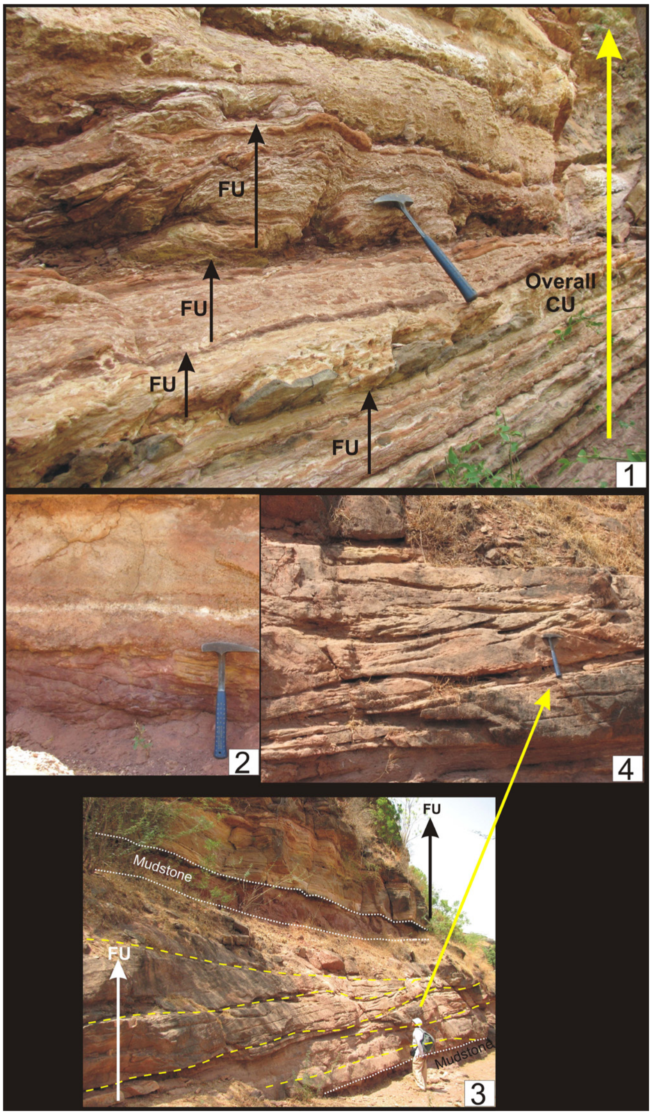

Fig. 5. Field photographs showing different sedimentological and lithofacies character of the lower Nimar Sandstone (lNS); (1) Interbedded sandston-siltstone-mudstone lithofacies representing tidal flat deposits, where individual cycle show fining upward (FU) character but overall it is coarsening upward (CU) at the upper part of the lNS at Bagh Cave section; Length of the hammer is 32 cm. (2) Gravelly mudstone lithofacies within the lNS at Bagh Cave section; length of the hammer is 32 cm. (3) Lensoidal sand bodies of lNS showing lateral shifting (LA element) and amalgamating character separated by mudstone unit; height of the person is 174 cm. (4) Lateral Accretion Surfaces (LA element) separated by muddy layer representing tidal point bar deposits; length of the hammer is 32 cm.

alternating calcareous mottled sandstone beds having intense burrowing in terms of number and diversity of trace fossils obliterating the primary physical structures, and relatively less bioturbated calcareous sandstone beds devoid of deformation. Beds are mostly planar cross-bedded and the thickness of the cross-beds varies from 15 cm to 40 cm. The uNS shows an erosional to sharp contact with the underlying ferruginous lNS and gradational contact with the overlying Nodular Limestone Formation (Fig. 6.1). The whole unit shows a gradual fining upward grain-size trend and is characterized by calcareous sandy-silty-muddy interbeds showing parallel lamination, lenticular and flaser bedding with abundant mm to cm-scale variously oriented burrow systems. In the upper part of this uNS fossil fragments, similar to those present in the overlying Nodular Limestone, are common. From the bottom to the top, the intensity of bioturbation increases, and the trace fossil also diversify. The different identifiable lithofacies in this uNS are: (i) Sandstone with the tidal bundle, (ii) Small scale cross-bedded calcareous sandstone, (iii) Interbedded calcareous sandstone-siltstone-mudstone, and (iv) Fossiliferous calcareous sandstone (Figs. 2 and 6.2).

SYSTEMATICS

Ichnogenus: *Arenicolites* (Salter, 1857)
(Figs.7.1 and 7.2)

Description: These ichnogenera are generally simple U-tubes without spreite, perpendicular to the bedding plane. These occur on the bedding plane as paired openings of the limbs. Limbs are 10–16 mm in diameter and usually spaced 4–15 mm apart. Limbs are commonly sand infilled, usually parallel, though sporadically converge slightly downwards or diverge upward. This ichnogenus occurs within the pebbly cross-bedded sandstone lithofacies of the lNS at Naingaon and Baghini river sections and also in the uNS of the Hathni River section (Fig. 2; Table 2).

Discussion: *Arenicolites* is normally restricted to intertidal to neritic deposits, although it has also been reported from deep water turbidites (Crimes *et al.,* 1974). Ichnogenus *Arenicolites* is generally vertical to sub-vertical dwelling structures made by suspension-feeding worms (Savrda, 2007, MacEachern *et al.,* 2007). According to Bromley (1996), *Arenicolites* is characterized as dwelling trace of the typically shallow marine realm with several deepwater instances (Bromley and Asgaard, 1979). In general, this trace fossil implies high energy intertidal to the sub-tidal condition of deposition (Fürsich, 1974). The occurrence of deeper and shallow burrows having comparable diameter implies that the rate of sedimentation was highly variable and animals lived at different depths within the sedimentary layers.

Ichnogenus: *Asterosoma* (von Otto, 1854)
(Figs.7.3 and 7.4)

Description: Radiating burrow systems varying between 9 cm to 20 cm in diameter are produced in calcareous sandstone lithofacies of the upper Nimar Sandstone (uNS) at the Bagh Cave section (Fig. 2; Table 2). There is 5 to 7 radial, tubular bulbous arms preserved, which radiate outwards from the central axis and taper towards blind extremities, parallel to the bedding plane and expand distally. The different tubes display longitudinal orientation and are variable in dimension, and numbers.

Discussion: *Asterosoma* is a frequent trace fossil reported from marginal marine to deep marine environments (Chamberlain, 1978; MacEachern and Hobbs, 2004; Neto de Carvalho and Rodrigues, 2007). *Asterosoma* has been interpreted as the dwelling burrow of a decapod crustacean and deposit-feeding burrow of a vermiform organism

Table 2. Interpretation of depositional environment of Nimar Sandstone based on sedimentology and trace fossils.

Lithounit	Sedimentary characters	Ichnogenera	Ichnofacies	Depositional Environment
upper Nimar Sandstone (uNS)	Cream coloured hard and compact calcareous sandstone, cycles of thinly bedded fine sandstone and mudstone-siltstone-fine sandstone cycles having intensive bioturbation	*Arenicolites* *Asterosoma* *Dactylophycus* *Skolithos* *Taenidium* *Teichichnus* *Thalassinoides* *Zoophycos*	Dominated by suspension feeder, dwelling feeder and deposit feeder; Mainly belongs to *Glossifungites* to *Cruziana* Ichnofacies	Supratidal- subtidal to inner neritic conditions of sedimentation
lower Nimar Sandstone (lNS)	Brick red coloured, ferruginous well persistent channelized sand bodies separated by thick bioturbated gravelly mudstones; herring bone cross cross strata, interference ripple, mud drapes, tidal bundles, 2-D ripples with reactivation surface.	*Arenicolites* *Diplocraterion* *Laevicyclus* *Ophiomorpha* *Skolithos* *Thalassinoides*	Dominated by suspension feeding organism; mainly belongs to *Skolithos* and *Glossifungites* ichnofacies	River dominated estuary to tide dominated estuary from base to top

also (Häntzschel, 1975). Miller and Knox (1985) reported *Asterosoma* from the Pennsylvanian lower tidal flat/tidal delta deposits. *Asterosoma* has also been reported from shoreface to offshore deposits (Frey and Howard, 1970; Vossler and Pemberton, 1989).

Ichnogenus: ***Dactylophycus*** (Miller and Dyer, 1878)
(Fig. 7.5)

Description: Burrow shows apparent branching in four directions, radiating and randomly branching from a central point. Palmate branched with unevenly pinching and swelling and limbs tapering at the end. The specimen shows full relief preservation on the bedding plane, smooth ornamentation, and elliptical cross-section. The palmate branch length varies from 1.5 to 3.4 cm and the maximum width increases at the center varying from 0.4 to 0.6 mm. The palmately branching form joins each other by thin pinching segments of 0.9 cm width. This trace fossil has been noted from calcareous sandstone lithofacies of the uNS at the Bagh Cave section (Fig. 2; Table 2).

Discussion: *Dactylophycus* is considered a radiating deposit-feeding trace of an unknown organism (Osgood, 1970). *Dactylophycus* is also considered a motion trace of arthropod or soft-bodied organisms (Trewin and McNamara, 1995). This ichnogenus has been reported from offshore deposits of the Upper Ordovician Eden Beds, Ohio, United States (Miller and Dyer, 1878; Osgood, 1970) and nearshore deposits of the Mississippian Pride Mountain Formation and the Hartselle Sandstone of Alabama, United States (Rindsberg, 1994). Recently, this ichnogenus has been reported from the offshore deposits of the Middle Jurassic Kaladongar Formation of Kachchh, India (Joseph *et al.,* 2012; Patel *et al.,* 2013).

Ichnogenus: ***Diplocraterion*** (Torell, 1870)
(Fig. 8.1)

Description: It occurs as vertical U-shaped cylindrical tubes with spreite. Burrows are 7-11 cm wide and 10 to 14 cm deep, however, the depth of penetration varies considerably. The diameter of the marginal burrows which are mostly parallel to subparallel and sometimes converging towards the mouth varies from 1.5 to 2.3 cm. Spreite are sporadically irregular and discontinuous, otherwise complete and almost parallel to each other preserved with full relief. Infilling is similar to the host rock material. This ichnofossil occurs within the cross-bedded sandstone lithofacies of the lNS at the Hathni River section (Fig. 2; Table 2).

Discussion: *Diplocraterion* is a sign of the activities of suspension-feeding organisms, including both vermiform organisms and diminutive arthropods like *Arenicolites* (Goldring, 1964; Fürsich, 1974; Gingras *et al.,* 1999). *Diplocraterion* is also a distinctive trace fossil in the soft ground *Skolithos* and firm-ground *Glossifungites* ichnofacies, being a common element of the distal end of the *Skolithos* ichnofacies (Pemberton *et al.,* 2001). This is also a typical marine form occurring in intertidal to the subtidal setting.

Ichnogenus: *Laevicyclus* (Quenstedt, 1879)
(Fig. 8.2)

Description: It is represented by downward tapering cylindrical burrows penetrating at right angles or slightly inclined into bedding planes, comprising two concentric circles visible on the bedding planes. The inner circles having a diameter of 3.3 cm are filled with ferruginous material, whereas the outer circles made up of siliceous sand have a diameter of 5 to 5.5 cm. Vertical burrows up to 25 cm in length are densely distributed in lNS at Hathni River section as well as in Naingaon section (Fig. 2; Table 2). It differs from *Monocraterion* in not possessing a series of concentric rings.

Discussion: This ichnogenus was also reported from the Bagh Group by Verma, (1971) and Kundal and Sanganwar (1998). Initially, the ichnogenus *Laevicyclus* was interpreted as an inorganic structure produced by escaping pressurized gasses and water trapped within sediments (Schmidt, 1934). Seilacher (1955), however, considered it as a trace fossil (feeding burrow) comparable to the dwelling shaft and scraping circles of the recent annelid *Scolecolepis*. Studied form preserved in areno-calcareous beds in vertical disposition may represent dwelling structure (domichnion).

Ichnogenus:*Ophiomorpha* (Lundgren, 1891)
(Fig.8.3)

Description: Essentially vertical, burrows show the variable diameter of offshoots emerging both at acute and obtuse angles with rough pitted wall structures which are

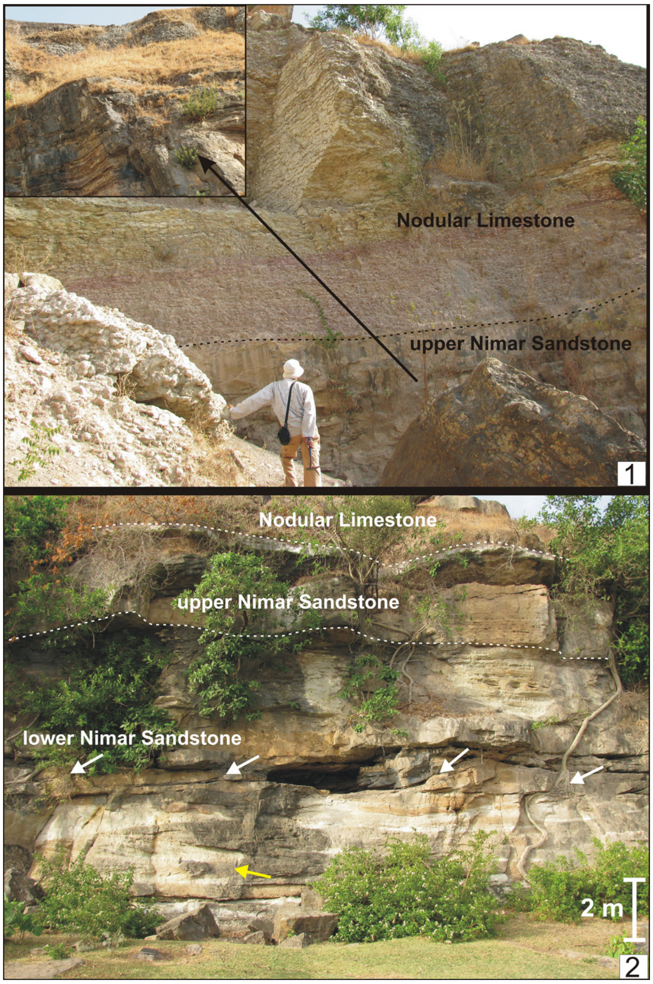

Fig. 6. Field photographs showing different sedimentological and lithofacies character of the upper Nimar Sandstone (uNS); (1) uNS making a relatively sharp contact with the overlying Nodular limestone at Bagh Cave section. (2) lNS with herringbone cross strata (Yellow arrow) and tidal bundle (white arrows) making a gradational contact with uNS at Hathni river section.

perpendicular to the burrow axis. The burrows are up to 14 cm in length and 1.4 to 1.8 cm wide preserved in vertical full relief. Because of the sandy substrate, nodos exterior is sometimes pitted and in parts obliterated and can only be seen in well-preserved forms as pitted structure. The burrows are hosted in cross-bedded sandstone lithofacies of lNS at the Hathni River section (Fig. 2; Table 2).

Discussion: *Ophiomorpha* is considered to have been produced by crustaceans (Frey *et al.*, 1978). According to Goldring *et al.* (2007), O*phiomorpha* today is being formed only in tropical/subtropical shallow marine sediments. Furthermore, it has been suggested that *Ophiomorpha* found in deep water turbidites may have been produced by relocated producers of shallow marine origin (Uchman and Gazdzicki, 2006; Goldring *et al.,* 2007). However, properly lined burrows may be ascribed to dwelling structures of inferred suspension-feeders (Pemberton *et al.,* 2001; MacEachern *et al.,* 2007). Saha *et al.*, (2010) reported *Ophiomorpha* from the Lameta Formation of Jabalpur area and interpreted it as burrows produced by suspension-feeding organisms.

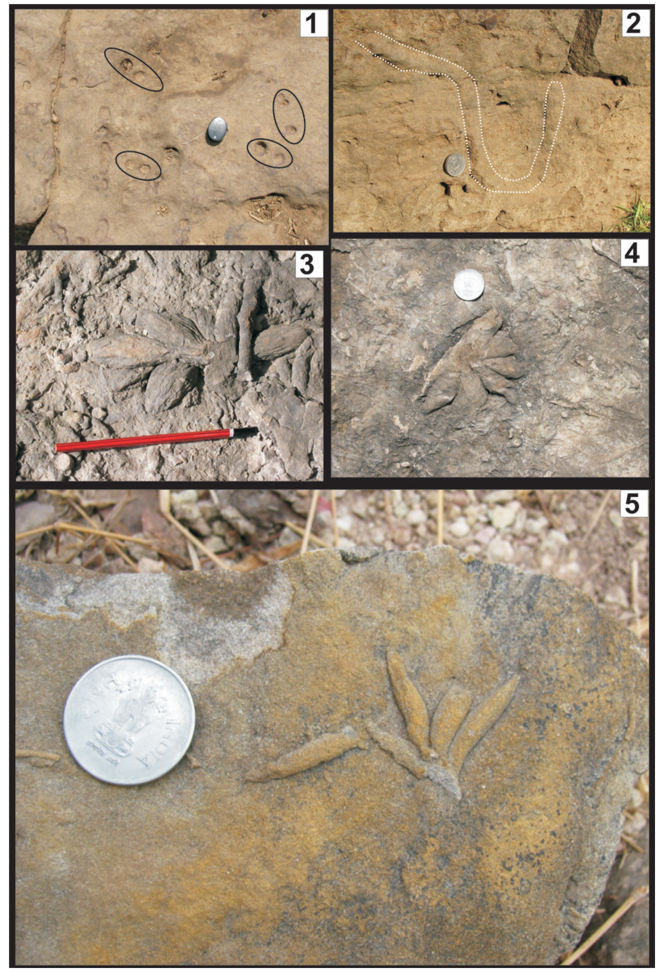

Fig. 7. (1) *Arenicolites* showing paired openings on bedding surface within lower Nimar Sandstone (lNS) along Baghini river, Bagh Cave; length of the lense is 4 cm. (2) U-shaped *Arenicolites* burrow within the upper Nimar Sandstone (uNS) at Hathni River section; diameter of the coin is 2.3 cm. (3 and 4) Two specimens of *Asterosoma,* showing flower like arms within the upper Nimar Sandstone (uNS) at Bagh Cave section; length of the pencil and diameter of the coin is 19 cm and 2.5 cm respectively. (5) *Dactylophycus* with palmate branches within the upper Nimar Sandstone (uNS) at Hathni River section; diameter of the coin is 2.5 cm.

Ichnogenus: *Skolithos* (Haldemann, 1840)
(Figs. 9.1 and 9.2)

Description: This is simple, essentially vertical tubes with lengths ranging from 55 to 60 cm. In the bedding plane aspect they comprise solitary circular traces. Skolithos range in size from 1.5 to 1.7 mm in diameter. The diameter within a single specimen is more or less constant but quite variable among different specimens. Burrows generally are not densely packed but are spaced 1.5 to 2 cm apart. This ichnogenus is well preserved at calcareous sandstone lithofacies and cross-bedded sandstone lithofacies of lNS and uNS at the Hathni River section and in lNS of Naingaon section (Fig. 2; Table 2).

Discussion: These ichnogenera have been reported to signify the activities of a wide variety of organisms, from fish to worms, insects, and anemones (Gingras *et al.,* 1999). These burrows are normally formed during a pause in sedimentation when suspension-feeding worms had time to

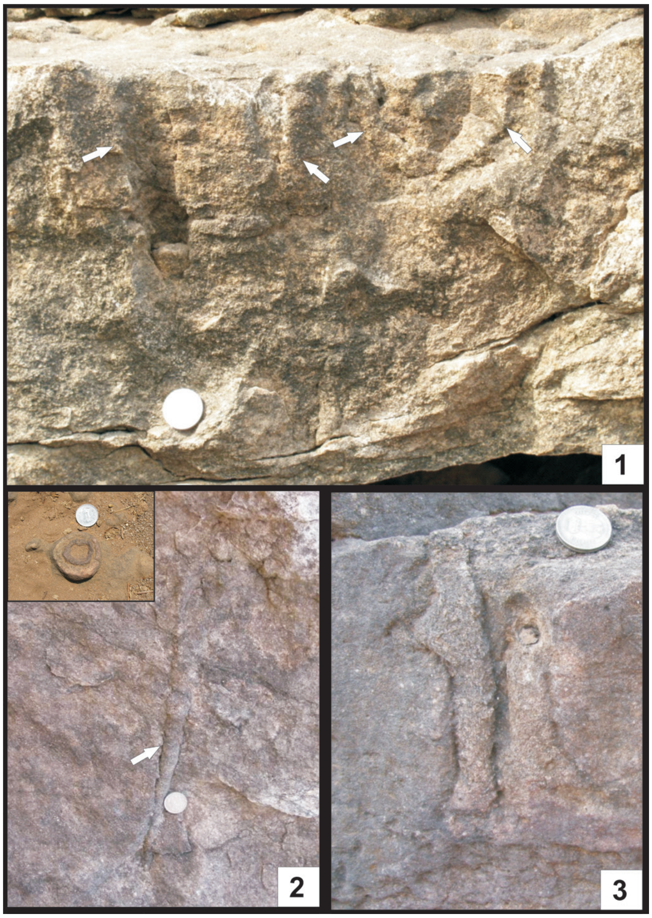

Fig. 8. (1) *Diplocraterion* within the lower Nimar Sandstone (lNS) at Hathni River section; diameter of the coin is 2.5 cm. (2) *Laevicyclus* represented by downward tapering pipe like structure within lower Nimar Sandstone (lNS) at Hathni River section; inset shows burrows normal to bedding plane along Baghini river, Bagh Cave; diameter of the coin is 2.5 cm. (3) Close up of a shaft of *Ophiomorpha* having pitted wall within the lower Nimar Sandstone(lNS) at Hathni River section; diameter of the coin is 2.3 cm.

colonize the seafloor (Hallam and Swett, 1966). According to Seilacher (1967), *Skolithos* is typical of the littoral zone but it also occurs in the neritic and occasionally bathyal zones (Crimes, 1970).

Ichnogenus:*Taenidium* (Heer, 1877)
(Fig. 9.3)

Description: Smooth-walled, unlined, cylindrical trace fossils with meniscate backfill. Diameter ranges from 4 to 7 mm having a length of 8.5 cm. They are horizontal, following bedding planes, sinuous and unbranched. Menisci are short and densely packed and segmented. This trace fossil has been found from fine-grained calcareous sandstone lithofacies of the uNS at the Hathni River section (Fig. 2; Table 2).

Discussion: It has been proposed that polychaetes (Gevers *et al.,* 1971), amphibians or reptiles (Ridgway, 1974), and arthropods (Morrissey and Braddy, 2004) can produce *Taenidium* burrows. The categorization of meniscate backfilled burrows is somewhat mystified. The main point of controversy with *Beaconites* has already been mentioned in trace fossil of the Lameta Formation by Saha *et al.* (2010). Keighley and Pickerill (1994) consider *Taenidium*

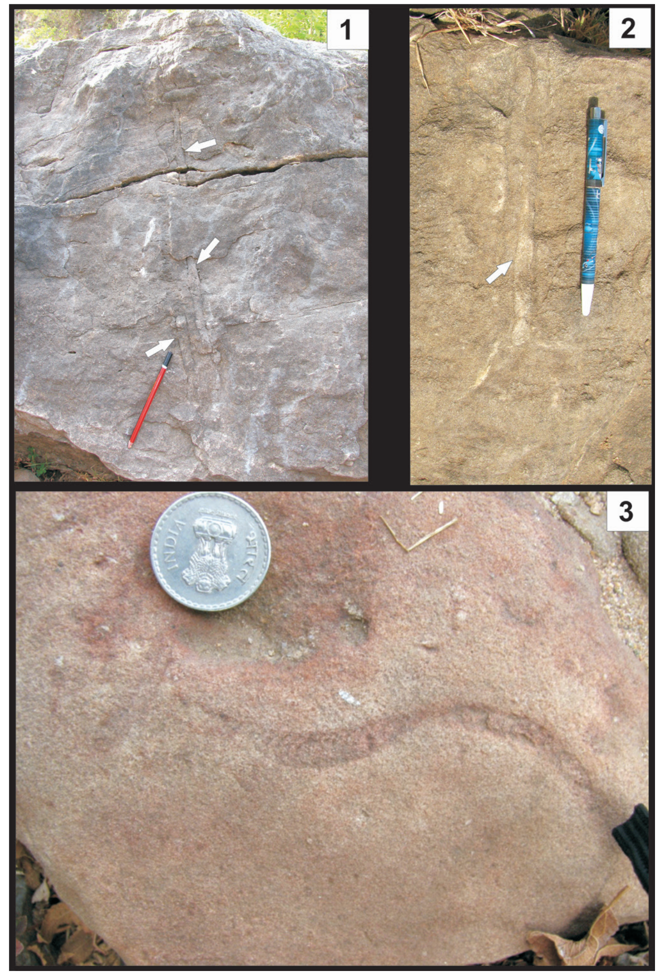

Fig. 9. (1) Vertical burrows having two pipes of *Skolithos* within lower Nimar Sandstone (lNS) at Hathni River section; length of the pencil is 17 cm. (2) Simple vertical *Skolithos* burrow within the upper Nimar Sandstone (uNS) at Hathni River section; length of the pen is 14 cm. (3) *Taenidium*, showing Spreiten structure within the upper Nimar Sandstone (uNS) at Hathni River section; diameter of the coin is 2.3 cm.

as unlined and *Beaconites* as lined burrow. Our specimen has an apparent lining formed by lateral merging of menisci. Taxonomical detail regarding *Taenidium* and other meniscate burrows has been elaborated by D'Alessandro and Bromley (1987), and Keighley and Pickerill (1994).

Ichnogenus: *Teichichnus* (Seilacher, 1955)
(Figs. 10.1 and 10.2)

Description: This burrow is rather simple formed by a series of long horizontal burrows.

It is composed of spreiten structures formed by horizontal displacement and oriented along the bedding plane. However, the structure is 1 to 2.5 cm wide, 6.5 cm long, slightly curvy otherwise unbranched, and disposed horizontally to the bedding. Successively younger spreites seem to be slight of lesser diameter and marginally displaced laterally. The spreites forming the structure are of variable thickness. It is preserved in full relief and indicates lateral shifting of burrows. This burrow is present in calcareous sandstone lithofacies of uNS at the Bagh Cave section (Fig. 2; Table 2).

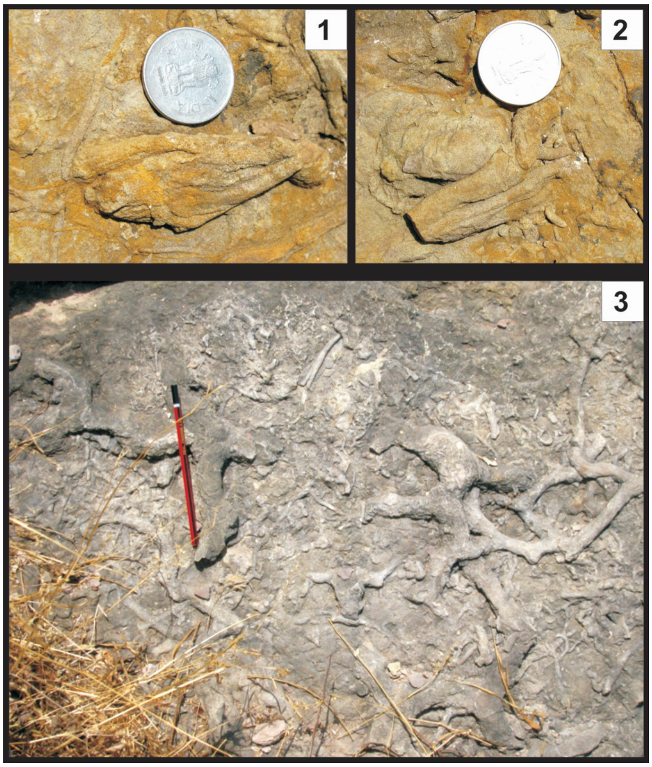

Fig. 10. (1 and 2) Two different specimens of *Teichichnus* burrow within the upper Nimar Sandstone (uNS) at Bagh Cave section; diameter of the coin is 2.5 cm. (3) Icnogenus *Thalassinoides* showing complex inter-connected burrow structure within the lower Nimar Sandstone (lNS) at Bagh Cave section; length of the pencil is 19 cm.

Discussion: According to Crimes (1976), *Teichichnus* occurs most frequently in neritic sediments, particularly around and immediately below the wave base. Chisholm (1970) considers them as a dwelling or feeding burrows. Fursich (1974) considers them as feeding burrows of deposit feeders. The presence of *Teichichnus* in association with calcareous sandstone lithofacies indicates its preference for a low energy environment, rich in organic matter. According to Mayoral *et al.* (2013), *Teichichnus* is very common in shallow, lower shoreface, and marginal marine depositional settings as wave or tide-dominated estuaries (bay-head delta, central basin, tidal flats).

Ichnogenus: *Thalassinoides* (Ehrenberg, 1944)
(Fig. 10.3)

Description: The branched burrows that do reveal at places Y-shaped and T-shaped and tree-shaped branching, tunnels are also very complexly interconnected, walls are remarkably cylindrical, may show irregular exterior, and seem to have passive infilling. The diameter of the main branches varies from 1 to 8 cm, at the point of bifurcation burrows show bulging patterns. Burrows are preserved both in full relief within the host beds as well as on the bedding planes forming box work–a type of network in which different sized burrows of different generations cross over each other. This burrow is characteristic of Nimar Sandstone, Nodular Limestone, and also Coralline Limestone. Burrows are much prominent and show an extensive network in the lNS and uNS of all the studied sections (Fig. 2; Table 2).

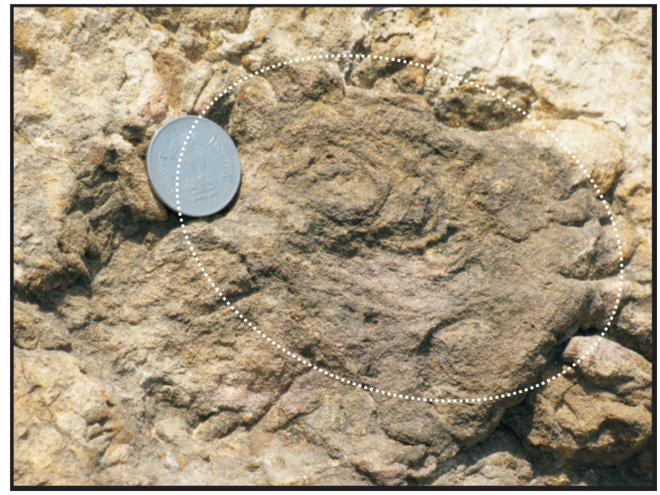

Fig. 11. Ichnogenus *Zoophycos* within the upper Nimar Sandstone (uNS) at Bagh Cave section; diameter of the coin is 2.5 cm.

Discussion: *Thalassinoides,* although a facies-crossing form, typically recorded in shallow-marine environments (e.g., Mángano and Buatois, 1991; Bromley, 1996), is also quite common in deep-marine and freshwater settings (e.g., Uchman, 1995). It is commonly produced by crustaceans (Frey *et al.,* 1984). In some cases, soft-bodied organisms have been suggested as trace makers (Myrow, 1995; Bromley, 1996). Generally, it is regarded as a feeding burrow system created in water-saturated cohesive substrate under an oxygenated and energetic environment (Ekdale, 1992). When found associated with sandy beds, it is generally interpreted as burrows of endobenthonic suspension feeders/scavengers (Fuersich, 1974). In the present study, a complex network of burrows and association with *Ophiomorpha* suggest that producer community was mainly endobenthonic suspension feeders/scavengers or rarely even deposit feeders. Presence of different sized burrows suggests that juvenile forms were also present.

Ichnogenus: *Zoophycos* (Massalango, 1855)
(Fig. 11)

Description: This trace fossil is preserved on the eroded bedding plane of calcareous sandstone lithofacies of uNS at the Bagh Cave section (Fig. 2; Table 2). These structures appear on the differentially eroded bedding planes as a series of irregularly thin crescents which are packed together within a semi-circular tube having a diameter of 5 to 6.7 cm. It is composed of a series of concentric ring types of structures.

Discussion: *Zoophycos* is a widely distributed facies-crossing form, known from marginal-marine (Miller, 1991) to shallow-marine (Marintsch and Finks, 1982), and deep-marine (Kotake, 1989) sediments. Most workers agree that *Zoophycos* is the organized deposit-feeding burrow system of an infaunal animal and these are probably formed by chemobiosynthetic-feeding activity of annelids or worms (Bromley, 1996; Sarkar *et al.,* 2009).

DISCUSSION

Previously, the Nimar Sandstone was generally considered a fluvial sequence (Pascoe, 1960; Robinson, 1967). However, Sarkar (1973) and Singh *et al.* (1981) attributed a tidal origin to it. Later Bose and Das (1986) considered the Nimar Sandstone as a product of transgressive storm and fair weather wave-dominated shelf sequence based on the lithofacies analysis. Later, Raiverman (1975), Chiplonkar *et al.* (1977), and Singh and Srivastava (1981) assigned it a marine origin, at least to the upper part of the Nimar Sandstone. However, none of these workers carried out the critical and systematic lithofacies analysis and most of the interpretations were based on gross lithology, body, and trace fossils. According to Singh and Srivastava (1981), the upper part of Nimar Sandstone (calcareous) and the Bagh Group were deposited in the shallow marine environment ranging from intertidal to shallow subtidal zone. Based on algal assemblage within the upper calcareous part of the Nimar Sandstone, Kundal and Sanganwar (1998) proposed deposition in tropical waters at a depth of 10- 12 m below the low tide levels, in a moderate energy setting with moderate turbulence and normal salinity of the water.

In the present study based on lithofacies and trace fossil analysis, we have subdivided the Nimar Sandstone into two, viz. the lower Nimar Sandstone (lNS) and the upper Nimar Sandstone (uNS). The basal part of the lNS is represented by a conglomerate and gravel-dominated sandstone. The gravel-dominated sandstone facies gradually becomes multi-storied large-scale cross-bedded sandstone complexes. The individual sandstone bodies persist laterally and show erosional transitions, lateral accretion elements (LA element), and amalgamating stories throughout the Bagh Cave and the Naingaon sections (Figs. 3 and 5; Table1 and 2). These characteristics imply sedimentation in channels that evolved through time generating a multistoried complex. However, the presence of interference ripples, herringbone cross-bedding with mudstone drapes and reactivation surfaces, tidal bundles, and ichnogerera, especially *Arenicolites, Skolithos,* and *Thalassinoides* indicate marine influence within the channels during the sedimentation (Figs. 2, 4 and 5; Table 2). An estuarine setting of sedimentation is, thus proposed for the lNS. The gravelly sandstone was deposited in a river-dominated environment affected by the tide in the landward part of the estuary, whereas the sandstones exhibiting LA element along with herringbone cross-bedding with mud drapes etc., were deposited in the sinuous middle part of the estuary depositing the tidal point bars (Dalrymple *et al.,* 1992; Reineck and Wunderlich, 1968; Cooper, 2001; Shukla and Bachmann, 2009; Verma and Shukla, 2020) (Fig. 12). These laterally shifting tidal point bar deposits, reactivation surfaces, tidal bundles are commonly separated by gravelly mudstone lithofacies showing deformation and bands of clays displaying lenticular and flaser bedding (Figs. 2 and 5; Table 2). These characteristics imply a pronounced influence of tidal action transporting the gravelly material onto the over bank muddy areas bordering the channels (Dalrymple *et al.,* 1992; Reineck and Wunderlich, 1968; Cooper, 2001; Shukla and Bachmann, 2009; Verma and Shukla, 2020) (Fig. 12). A complete evolution of a river-dominated estuary to the tide-dominated estuary from the base of the lNS to its upper part thus is envisaged.

In the Bagh Cave section, the sandy channelized lithofacies are sharply followed by a prominent unit of interbedded sandstone-siltstone-mudstone lithofacies displaying wavy and flaser bedding, ripple cross lamination, bioturbated mudstone along with some fossil fragments (Fig. 5.1). The mudstone to fine sand units represents tidal flat cycles. It is coarsening upward indicates rising sea levels, which led mudflats to be succeeded by mixed flats and capped by sand flats (see Reineck, 1972; Reineck and Singh, 1973; Reineck and Wunderlich, 1968; Chakraborti, 2005; Dalrymple *et al.,* 2012). We envision that the estuarine channels were bordered by extensive tidal flat areas. Primary sedimentary structures, lithofacies constitution, and trace fossils suggest the lNS represent subtidal conditions within the estuarine channels and the intertidal conditions onto the bordering tidal flats (Fig. 12 and Table 2). Hitherto, the lower part of the Nimar Sandstone has been traditionally interpreted as a product of a fluvial setting (Bhattacharya *et al.,* 2020 and references therein).

The overlying calcareous sandstone lithofacies of uNS contains a variety of trace fossils both in frequency and diversity (Fig. 2 and Table 2) and is characterized by cross-bedding and ripple cross-lamination with mud drapes and tidal bundles. With further sea-level rise, the intertidal zone passed into the subtidal zone and sedimentation shifted to the estuary mouth as a shoaling bar and tidal channels. The presence of a variety of trace fossils along with calcareous mudstones indicates, a subtidal condition of deposition in an inner neritic setting (Fig. 12 and table 2).

The overall trend of the grain size in the Nimar Sandstone is that of fining upwards with the top becoming calcareous. Lithofacies and ichnofacies characteristic indicates that the whole of the Nimar Sandstone was deposited under rising sea level condition forming a Transgressive Systems Tract (TST) deposit of a 3rd order sea-level cycle. TST cycle is composed of at least 5 parasequences (sand bodies 1 to 5 of Fig. 3). Each parasequence is fining upward where sandstone is capped by the gravelly mudstone in the basal part of the lNS, which is brick red, and by tidal flat cycles in the upper part of the lNS which is red to yellow buff in color, in which the Bagh caves were excavated. The top sandstone body numbering 5 in Fig. 3, is calcareous and contains a variety of ichnofossils and body fossils, and gradationally is overlain by the Nodular Limestone having a variety of fauna of open marine affinity (Figs. 2, 3 and Table 2).

The interpretation based on the lithofacies analysis is further corroborated by the ichnoassemblage of the lNS and uNS. The diversity and frequency of trace fossils increase from the lNS to uNS (Fig. 2; Table 2). The lNS is characterized by *Arenicolites, Diplocraterion, Laevicyclus, Ophiomorpha, Skolithos,* and *Thalassinoides* ichnogenera. Trace fossil assemblages of lNS are dominated by suspension-feeding organisms and mostly belong to *Skolithos* and *Glossifungites* ichnofacies (Table 2). On the other hand, the uNS is characterized by ichnogenera like *Arenicolites, Asterosoma, Dactylophycus, Skolithos, Taenidium, Teichichnus, Thalassinoides,* and *Zoophycos*. Trace fossil assemblages of uNS are dominated by suspension feeders, dwelling feeders, and deposit feeders and are mostly belong to *Glossifungites*

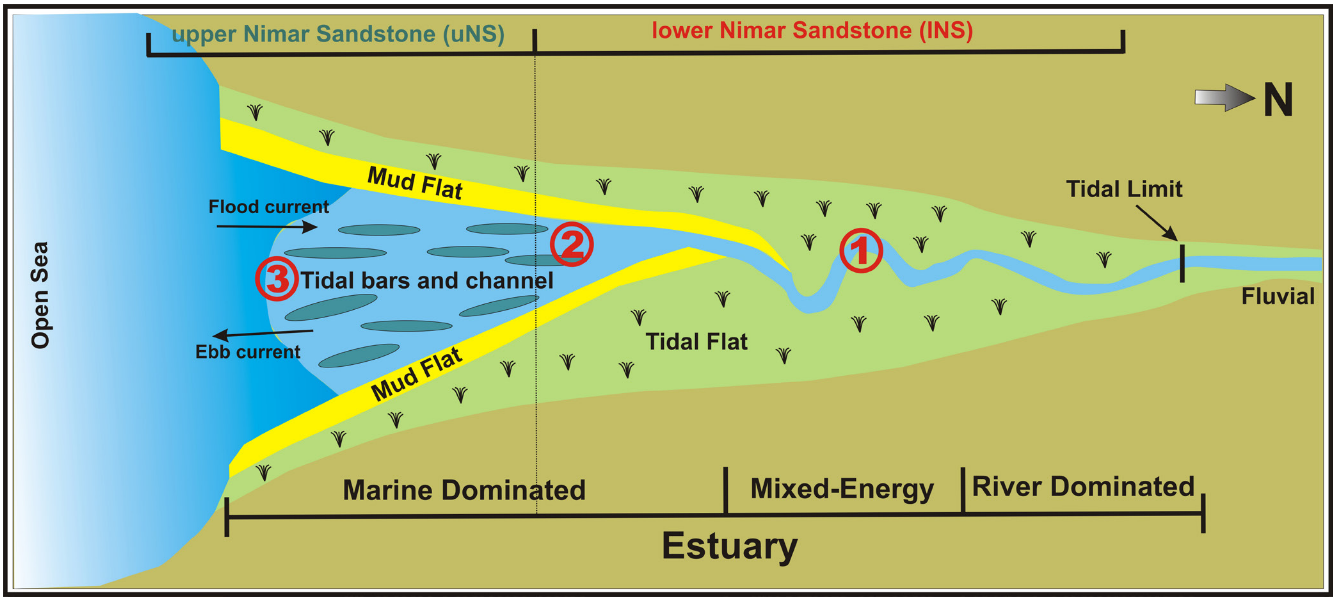

Fig. 12. Schematic depositional model of a tide dominated estuary proposed for the deposition of the lower Nimar Sandstone (lNS) and the upper Nimar Sandstone (uNS) respectively, with probable location of studied sections with respect to geomorphic domain of sedimentation are depicted as 1) Naingaon section, 2) Hathni River section and 3) Bagh Cave section.

to *Cruziana* Ichnofacies (Table. 2). These ichnofacies are the characteristics of intertidal to subtidal environments.

Another clear distinction between the lNS and uNS is apparent in their faunal contents. Characteristically, the (lNS) is scantily fossiliferous (see Table-2 of Bhattacharya et al., 2020 and Table-6 of Bhattacharya *et al.,* 2021 and references therein) whereas; the (uNS) is abundantly fossiliferous (Bhattacharya *et al.,* 2020, 2021).

Thus, the succession of the Nimar Sandstone is a classic expression of a river-dominated estuary to a tide-dominated estuary graduating to shallow inner neritic marine environment condition of deposition (Fig. 12). The rivers converging to the estuaries had provenance in the Aravalli and Precambrian basement (Ahmed, 1992). Because of progressive transgression, the clastic supply from land got depleted, which induced the precipitation of carbonates of the calcareous sandstone of the uNS and the overlying Nodular Limestone (Table 1).

CONCLUSIONS

Sedimentological characters integrated with the ichno-assemblage reveal that the Nimar Sandstone of the Cenomanian age can be divided into the ferruginous lower Nimar Sandstone (lNS) and calcareous upper Nimar Sandstone (uNS).

An environment of deposition from the base to the top of lower Nimar Sandstone shifted from a river-dominated estuary to a tide-dominated estuary.

The upper Nimar Sandstone was deposited under subtidal to inner neritic conditions at the funnel-shaped estuary mouth where carbonate could precipitate (Fig. 12).

The whole succession of the Nimar Sandstone represents a Transgressive Systems Tract (TST) of a 3rd order sea-level cycle.

The ichnofossil assemblage of the Nimar Sandstone reveals that endobenthic worm-like organisms and arthropods were dominant among the faunal community that churned the sediments under shallow marine conditions in semi-consolidated foreshore to shoreface and subtidal open marine conditions.

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REFERENCES

Acharya, S.K. and Lahiri, T.C. 1991. Cretaceous palaeogeography of the Indian subcontinent: a review. Cretaceous Research, 12: 3-26.

Badve R.M. and Ghare M.A. 1980. Ichnofauna of Bagh Beds from Deva river valley, south of Narmada. Biovigyanam, 6: 121-130.

Badve, R.M. 1987. A reassessment of Stratigraphy of Bagh Beds, Barwah area, Madhya Pradesh, with description of trace fossils. Journal Geological Society of India, 30: 106-120.

Bardhan, S., Gangopadhyay, T.K. and Mandal, U. 2002. How far India drift during the Late Cretaceous?-*Placenticeras kaffrarium* Etheridge, 1904 (Ammonoidea) used as a measuring tape. Sedimentary Geology, 147: 193-217.

Bhattacharya, B., Jha, S. and Mondal, P. 2020. Palaeogeographic reconstruction of a fluvio-marine transitional system in Narmada rift basin, India- Implications on Late Cretaceous global sea-level rise. Journal of Palaeogeography, 9: 1-22.

Bhattacharya, B., Halder, K., Jha, S., Mondal, P. and Ray, R. (2021). Stratigraphy, Sedimentology and Paleontology of Late Cretaceous Bagh Beds, Narmada Valley, Central India: A Review. Mesozoic Stratigraphy of India, 623-657.

Biswas, S.K. 1987. Regional tectonic framework, structure and evolution of the western marginal basins of India. Tectonophysics, 135: 307-327.

Blandford, W.T. 1869. On the geology of the Taptee and Lower Nerbudda valleys and some adjoining districts. Memoirs of the Geological Survey of India, 6: 163-384.

Bose, P.N. 1884. Geology of the Lower Narmada Valley between Nimawar and Kawant. Memoirs of Geological Survey of India, 21(1): 72p.

Bose, P.K. and Das, N.G. 1986. A transgressive storm and fair weather wave dominated shelf sequence: Cretaceous Nimar Formation, Chakrud, Madhya Pradesh, India. Sedimentary Geology, 46: 147-167.

Bromley, R.G. and Asgaard, U. 1979. Triassic freshwater ichnocoenoses from Carlsberg Fjord, East Greenland. Palaeogeography Palaeoclimatology Palaeoecology, 28: 39-80.

Bromley, R.G. 1996. Trace Fossils: Biology, Taphonomy and Applications, 2nd edition. Chapman and Hall, London, 361 pp.

Chakrabarti, A. 2005. Sedimentary structures of tidal flats: A journey from coast to inner estuarine region of eastern India. Journal of Earth System Science, 114 (3): 353-368.

Chamberlain, C.K. 1978. Recognition of trace fossils in cores. In: Basan, P. (Ed.), Trace fossil concepts: SEPM: Short Course, 5, pp. 133-183.

Chiplonkar, G.W. and Badve, R.M. 1969. Trace fossils from Bagh Beds. Journal of the Palaeontological Society of India, 14(1): 1-10.

Chiplonkar, G.W. and Ghare, M.A. 1975. Occurrence of Keckia annulata Glocker, in Bagh Beds of Narmada valley. Current Science, 44(16): 583-584.

Chiplonkar, G.W., Badve, R.M. and Ghare, M.A. 1977. On the stratigraphy of the Bagh Beds of the Lower Narbada Valley. In Venkayachala, B.S., Sastri, V.V. (eds.), Proceedings of the IVth Colloquium on Indian Micropalaeontology and Stratigraphy. Institute of Petroleum Exploration, Dehra Dun, 209-216.

Chisholm, J.I. 1970. Teichichnus and related trace fossils in the Lower Carboniferous at St. Monance, Scotland. Bulletin of the Geological Survey of Britain, 32: 21-51.

Cooper, J.A.G. 2001. Geomorphological variability among microtidal estuaries from wave- dominated South African coast. Geomorphology, 40: 99-122.

Crimes, T.P. 1970. The significance of trace fossils in sedimentology, stratigraphy and palaeoecology with examples from Lower Palaeozoic strata. In Crimes, T.P., Harper, J.C. (eds.), Trace Fossils: Geological Journal Special Issue, vol. 3, pp. 101-126.

Crimes, T.P. 1974. Colonisation of the early ocean floor. Nature, 248: 328-330.

Crimes, T.P. 1976. Trace fossils from the Bray Group (Cambrian) at Howth Company Dublin. Bulletin of the Geological Survey of Ireland, 2: 53-67.

D'Alessandro, A. and Bromley, R.G. 1987. Meniscate trace fossils and the Muensteria-Taenidium problem., Palaeontology, 30: 743-763.

Dalrymple, R.W., Zaitlin, B.A. and Boyd, R. 1992. Estuarine facies models: conceptual basis and stratigraphic implications. Journal of Sedimentary Petrology, 62: 1130-1146.

Dalrymple, R.W., Mackay, D.A., Ichaso, A.A. and Choi, K.S. 2012. In R.A. Davis, Jr. and R.W. Dalrymple (eds.), Principles of Tidal Sedimentology, Springer.

Dassarma, D.C. and Sinha, N.K. 1975. Marine Cretaceous Formations of the Narmada Valley (Bagh Beds), Madhya Pradesh and Gujarat., Memoirs of the Geological Survey of India, Palaeontologia Indica- New Series, 42: 1-12.

Ehrenberg, K. 1944. Ergänzende Bemerkungen zu den seinerzeit ausdem Miozän von Burgschleinitz beschrieben Gangkernen und Bauten dekapoder Krebse. Paläntologische Zeitschrift, 23: 345-359.

Ekdale, A.A. 1992. Muckraking and mudslinging: the joys of deposit feeding. In: Maples, C.G., West, R.R. (Eds.), Trace Fossils., The Paleontological Society, Short Courses in Paleontology- 5, 145-171.

Ekdale, A.A., Bromley, R.G.,Knaust, D., 2012. The ichnofabric concept. In: Knaust,D., Bromley, R.G. (Eds.), Trace Fossils as Indicators of Sedimentary Environments. Developments in Sedimentology, vol. 64. Elsevier, Amsterdam, pp. 139–155.

Frey, R.W. 1970. Trace fossils of Fort Hays Limestone Member of Niobrara Chalk (Upper Cretaceous), west-central Kansas. University of Kansas, Paleontological Contributions, 53: 1-41.

Frey, R.W., Howard, J.D. and Pryor, W.A. 1978. *Ophiomorpha*: its morphologic, taxonomic, and environmental significance. Palaeogeography Palaeoclimatology Palaeoecology, 23: 199-223.

Fürsich, F.T. 1974a. Corallian (Upper Jurassic) trace fossils from England and Normandy. Stuttgarter Beitra¨ ge zur Naturkunde, Serie B (Geologie und Paläontologie), 13: 1-51.

Fürsich, F.T. 1974b. On Diplocraterion Torell 1870 and the significance of morphological features in vertical, spreiten-bearing, U-shaped trace fossils. Journal of Paleontology, 48: 11-28.

Gangopadhyay, T.K. and Bardhan, S. 2000. Dimorphism and a new record of Barroisiceras de Grossouvre (Ammonoidea) from the Coniacian of Bagh, central India., Canadian Journal of Earth Sciences, 37: 1377-1387.

Ganguly, T. and Bardhan, S. 1993. Dimorphism in *Placenticeras mintoi* from the Upper cretaceous Bagh Beds, central India., Cretaceous Research, 14: 757-756.

Gevers, T.W., Frakes, L.A., Edwards, L.N. and Marzolf, J.E. 1971. Trace fossils in the Lower Beacon sediments (Devonian), Darwin Mountains, southern Victoria Land, Antarctica. Journal of Paleontology, 45: 81-94.

Gingras, M.K., Pemberton, S.G., Saunders, T.D.A. and Clifton, H.E., 1999. The ichnology of modern and Pleistocene brackish-water deposits at Willapa Bay, Washington: variability in estuarine settings. Palaios, 14: 352-374.

Goldring, R. 1964. Trace fossils and the sedimentary surface in shallow marine sediments. Developments in Sedimentology, 1: 136-143.

Goldring, R., Cade´e, G.C. and Pollard J.E. 2007. Climatic Control of Marine Trace Fossil Distribution. In Miller W III (eds), Trace fossils: concepts, problems, prospects. Elsevier, New York, p 531-544.

Haldeman, S. T. 1840. Supplement to number one of A monograph of the Limniades, or freshwater univalvia shells of North America, containing descriptions of apparently new animals in different classes, and the names and characters of the subgenera in Paludina and Anculosa, Philadelphia, 3p.

Hallam, A. and Swett, K. 1966. Trace fossils from the Lower Cambrian Pipe Rock of the north-west Highlands., Scottish Journal of Geology, 2: 101-106.

Häntzschel, W. 1975. Trace fossils and problematica. In Teichert, C. (eds.), Treatise on Invertebrate Paleontology, part W, Miscellanea, Supplement I. Geological Society of America and University of Kansas Press.

Heer, O. 1877. *Flora Fossilis Helvetiae. Vorweltliche Flora der Schweiz,* J. Wurster and Comp., Zürich, 182 pp.

Jaitly, A.K. and Ajane, R. 2013. Comments on *Placenticeras mintoi* (Vredenburg, 1906) from the Bagh Beds (Late Cretaceous), Central India with Special Reference to Turonian Nodular Limestone Horizon., Journal Geological Society of India, 81: 565-574.

Joseph, J.K., Patel, S.J. and Bhatt, N.Y. 2012. Trace fossil assemblages in mixed siliciclastic-carbonate sediments of the Kaladongar Formation

(Middle Jurassic), Patcham Island, Kachchh, Western India. Journal of Geological Society of India, 80: 189-214.

Keighley, D.G. and Pickerill, R.K. 1994. The ichnogenus Beaconites and its distinction from Ancorichnus and Taenidium., Palaeontology, 37, 305–337.

Keller, G., Nagori, M.L., Chaudhary, M., Reddy, A.N., Jaiprakash, B.C., Spangenberg, J. E., Mateo, P. and Adatte, T. 2021. Cenomanian-Turonian sea-level transgression and OAE 2 deposition in the Western Narmada Basin, India. Gondwana Research, 94: 73-86.

Kennedy, W.J., Phansalkar, V.G. and Walaszczyk, I. 2003. Prionocyclus germari ([Reuss, 1845]), a Late Turonian marker fossil from the Bagh Beds of central India. Cretaceous Research, 24: 433-438.

Khosla, A., Kapur, V.V., Sereno, P.C., Wilson, J.A., Wilson, G.P., Dutheil, D., Sahani, A., Singh, M.P., Kumar, S. and Rana, R.S. 2003. First Dinosaur remains from the Cenomanian-Turonian Nimar Sandstone (Bagh Beds), District Dhar, Madhya Pradesh, India. Journal of the Palaeontological Society of India, 48: 115-127.

Kotake, N. 1989. Paleoecology of the *Zoophycos* producers. Lethaia, 22: 327-341.

Kumar, S., Pathak, D.B., Pandey, B., Jaitly, A.K. and Gautam, J.P. 2018. The age of the Nodular Limestone Formation (late cretaceous), Narmada Basin, Central India. Journal of Earth System Science, 127: 1-7.

Kumari, V., Tandon, S.K., Kumar, N. and Ghatak, A. 2020. Epicontinental Permian-cretaceous seaways in Central India: the debate for the Narmada versus Godavari rifts for the Cretaceous-Tertiary incursion. Earth Science Review, 211 (1-24): 103284.

Kundal, P, and Sanganwar, B.N. 1998. Stratigraphy and palichnology of Nimar Sandstone, Bagh Beds of Jobat area, Jhabua district, Madhya Pradesh., Journal Geological Society of India, 51(5): 619-634.

Kundal, P. and Sanganwar, B.N. 2000. Ichnofossils from Nimar Sandstone Formation, Bagh Group of Manawar area, Dhar district, Madhya Pradesh., Memoir of the Geological Society of India, 46: 229-243.

Lundgren, B. 1891. Studier öfver fossilförande lösa block., Geologiska Föreningen i Stockholm Förhandlinger,13: 111-121.

MacEachern, J.A. and Hobbs, T.W. 2004. The ichnological expression of marine and marginal marine conglomerates and conglomeratic intervals, Cretaceous Western Interior Seaway, Alberta and northeastern British Columbia., Bulletin of Canadian Petroleum Geology, 52: 77-104.

MacEachern, J.A., Pemberton, S.G., Gingras, M.K. and Bann, K.L. 2007. Ecological and evolutionary controls on the composition of marine and lake ichnofacies. In Miller W III (eds.), Trace fossils: concepts, problems, prospects. Elsevier, New York, p 531-544.

Mángano, M. G. and Buatois, L. A. 1991. Discontinuity surfaces in the Lower Cretaceous of the High Andes (Mendoza, Argentina): trace fossils and environmental implications. Journal of South American Earth Sciences, 4: 215-229.

Marintsch, E. J. and Finks, R. M. 1982. Lower Devonian ichnofacies at Highland Mills, New York and their gradual replacement across environmental gradients. Journal of Paleontology, 56: 1050-1078.

Massalongo, A. 1855. *Zoophycos*, novum genus plantarum fossilium. Typis Antonellianis, Verona, pp.44-52.

Mayoral, E., Ledesma-Vazquez, J., Baarli, B.G., Santos, A., Ramalho, R., Cachão, M., Da Silva, C.M. and Johnson, M.E. 2013. Ichnology in oceanic islands; case studies from the Cape Verde Archipelago. Palaeogeography Palaeoclimatology Palaeoecology, 381-382: 47-66.

Miller, M. F. 1991. Morphology and paleoenvironmental distribution of Paleozoic *Spirophyton* and *Zoophycos:* implications for the *Zoophycos* ichnofacies. Palaios, 6: 410-425.

Miller, S.A. and Dyer, C.B. 1878. Contributions to paleontology, no. 1. Cincinnati Society of Natural History, 1: 24-39.

Miller, M.F. and Knox, L.W. 1985. Biogenic structures and depositional environments of a Lower Pennsylvanian coal-bearing sequence, northern Cumberland Plateau, Tennessee, U.S.A. In Curran, H.A. (eds.), Biogenic Structures and Their Uses in Interpreting Depositional Environments, SEPM Special Publication No. 35, pp. 67-97.

Mohabey, D.M. 1996. Depositional environments of Lameta Formation (Late Cretaceous) of Nand-Dongargaon inland basin, Maharashtra: the fossil and lithological evidences. Memoir of the Geological Society of India, 37: 363-386.

Morrissey, L.B. and Braddy, S.J. 2004. Terrestrial trace fossils from the Lower Old Red Sandstone, southeast Wales. Geological Journal, 39: 315-336.

Myrow, P.M. 1995. *Thalassinoides* and the enigma of Early Paleozoic open framework burrow systems. Palaios, 10: 58-74.

Nayak, K.K. 2000. Additional trace fossils from the Nimar Sandstone, Bagh Group, Jhabua district, Madhay Pradesh. Bulletin Oil and Natural Gas commission India, 37(1): 189-197.

Neto de Carvalho, C. and Rodrigues, N.P.C. 2007. Compound Asterosoma ludwigae Schlirf, 2000 from the Jurassic of the Lusitanian Basin (Portugal): conditional strategies in the behaviour of Crustacea. Journal of Iberian Geology, 33: 295-310.

Osgood, R.G. 1970. Trace fossils of the Cincinnati area. Palaeontographica Americana, 6: 281-444.

Pascoe, E.H. 1960. A manual of the Geology of India and Burma., Geological Survey of India, Calcutta. Vol. II. pp-1338.

Patel, S.J., Joseph, J.K. and Bhatt, N.Y. 2013. Sequence stratigraphic analysis of the mixed siliciclastic-carbonate sediments (Middle Jurassic) of the Patcham Island, Kachchh, Western India: An ichnological approach. Geological Society of India, Special Publication: 84-111.

Pemberton, S.G., MacEachern, J.A. and Frey, R.W. 1992. Trace fossil facies models: environmental and allostratigraphic significance. In Walker, R.G. and James, N. (eds.), Facies Models: Response to Sea Level Change., Geological Association of Canada, St. John's Newfoundland, pp. 47-72.

Pemberton, S.G., Spila M., Pulham, A.J., Saunders, T., MacEachern, J.A., Robbins, D. and Sinclair, I.K. 2001. Ichnology and sedimentology of shallow to marginal marine systems: Ben Nevis and Avalon Reservoirs, Jeanne d'Arc Basin., Geological Association of Canada, St. John's Newfoundland, Short Course Notes-15, 353 pp.

Quenstedt, F. A. 1879. Petrefactenkunde Deutschlands. 1. Abth., Vol. 6: Korallen. Die Röhren-und Steinkorallen. L. F. Fues, Leipzig: 1093 p.

Raiverman, V. 1975. Facies transition among Nimar, Bagh and Lameta Beds. In "Recent Researches in Geology" V.K. Verma (eds.), Hindustan Publication Corporation, New Delhi, 123-139.

Reineck, H.E. and Singh, I.B. 1973. Depositional Sedimentary Environments. Springer-Verlag, Berlin, New York, 439p.

Reineck, H.E. and Wunderlich, F. 1968. Classification and origin of f1aser and lenticular bedding. Sedimentology, 11: 99-104.

Reineck, H.E. 1972. Tidal flats. SEPM Special Publication, 16: 146- 149.

Ridgway, J.M. 1974. A problematical trace fossil from the New Red Sandstone of south Devon. Proceedings of the Geologists' Association, 85: 511-517.

Rindsberg, A. K. 1994. Ichnology of the Upper Mississippian Hartselle Sandstone of Alabama, with notes on other Carboniferous formations. Geological Survey of Alabama, Bulletin, 158: 1-107 pp. Tuscaloosa, Alabama.

Robinson, P. L. 1967. The Indian Gondwana Formations- A review. First Symposium on Gondwana Stratigraphy, Ar Del Plata, Argentina, 201-268.

Rode, K.P. and Chiplonkar, G.W. 1935. A contribution to the stratigraphy of Bagh Beds. Current Science, 4(5): 322-323.

Roy Chowdhury, M.K. and Sastri, V.V. 1962. On the revised classification of Cretaceous and associated rocks of Man river section of lower Narmada valley. Record of Geological Survey of India, 91(2): 283-301.

Ruidas, D.K., Paul, S. and Gangopadhyay, T.K. 2018. A reappraisal of stratigraphy of Bagh Group of rocks in Dhar District, Madhya Pradesh with an outline of origin of nodularity of Nodular Limestone Formation. Journal of the Geological Society of India, 92:19-26.

Saha, O., Shukla, U.K. and Rani, R. 2010. Trace Fossils from the Late Cretaceous Lameta Formation, Jabalpur Area, Madhya Pradesh: Paleoenvironmental Implications. Journal of the Geological Society of India, 76: 607-620.

Saha, O. 2013. Lithofacies and sedimentation pattern of Lameta and Bagh Beds (Upper Cretaceous), Central India., Unpublished Ph.D. Thesis, Banaras Hindu University, 210 pp.

Sahni, A. 1983. Upper cretaceous Palaeobiogeography of Peninsular India and the Cretaceous-Paleocene transition: the vertebrate evidence. In: Symposium on Cretaceous of India: Palaeoecology, Palaeogeography and Time Boundaries, pp. 128-140.

Salter, J.W. 1857. On annelide-burrows and surface markings from the Cambrian rocks of the Longmynd. Quaterly Journal of the Geological Society of London, 13: 199-206.

Sanganwar, B.N. and Kundal, P. 1997. Ichnofossils from Nimar Sandstone Formation, Bagh Group of Barwha area, Khargone district, Madhya Pradesh., Gondwana Geological Magazine, 12(1): 47-54.

Sarkar, S. K. 1973. Sedimentology of the Nlmara-Bagh-Lameta Complex around Awaldaman and Bagh areas, Dhar district, Madhya Pradesh., Unpublished Ph.D. Thesis, Jadavpur University, 190 pp.

Sarkar, S., Ghosh, S.K. and Chakraborty, C. 2009. Ichnology of a Late Paleozoic ice marginal shallow marine succession: Talchir Formation, Satpura Gondwana Basin, central India., Palaeogeography Palaeoclimatology Palaeoecology, 283: 28-45.

Savrda, C.E. 2007. Trace Fossils and Marine Benthic Oxygenation. In Miller W III (eds.), Trace fossils: concepts, problems, prospects. Elsevier, New York, p 531-544.

Schmidt, M. 1934. *Cyclozoon philippi* und verwandte Gebilde: Heidelberger. Akademie der Wissenschaften, mathematisch-naturwissenschaftliche Klasse, Sitzungsberichte., 31 pp.

Seilacher, A. 1955. Spuren und Fazies im unterkambrium. In Schindewolf, O. H. and Seilacher, A. (eds.). *Beitr¨age sur Kenntnis des Kambriums in der Salt Range (Pakistan)*.Akademie derWissenschaften und der Literatur zuMainz, mathematisch-naturwissenschaftliche Klasse, Abhandlungen, 10: 86-143.

Seilacher, A. 1967. Bathymetry of trace fossils. Marine Geology, 5: 413-428.

Shukla, U. K. and Bachmann, G. H. 2007. Estuarine sedimentation in the Stuttgart Formation (Carnian, Late Triassic) South Germany. Neues Jahrbuch für Geologie und Paläontologie Abhandlungen, 243: 305-323.

Shukla, U. K. and Srivastava, R. 2008. Lizard eggs from the late Cretaceous Lameta Formation of Jabalpur, central India with interpretation of depositional environments of nest-bearing horizon, Cretaceous Research, 29: 674-686.

Singh, I.B. 1981. Palaeoenvironment and Palaeogeography of Lameta Group sediments (Late Cretaceous) in Jabalpur area, India. Journal of the Palaeontological Society of India, 26: 38-53.

Singh, S.K., and Dayal, R.M. 1979. Trace fossils and environment of deposition of Nimar Sandstone, Bagh Beds., Journal of the Geological Society of India, 20: 234-239.

Singh, G. and Ghosh, R.N. 1977. Nimar Sandstone In. Lexicon of Gondwana Formation of India. Geological Survey of India Miscellaneous Publications, 36: 62-63.

Singh, S.K. and Srivastava, H.K. 1981. Lithostratigraphy of Bagh Beds and its correlation with Lameta Beds. Journal of the Palaeontological Society of India, 26: 77-85.

Sridhar, A.R. and Tewari, H.C. 2001. Existence of a sedimentary graben in the western part of Narmada zone: seismic evidence. Journal of Geodynamics, 31: 19-41.

Srivastava, R., Patnaik, R., Shukla, U.K. and Sahni, A. 2015. Crocodilian Nest in a Late Cretaceous Sauropod Hatchery: A Case of Possible Predation from the Type Lameta Ghat Locality, Jabalpur, India. PLoS ONE, 10 (12): e0144369.

Torell, O.M. 1870. Petrificata Suecana Formationis Cambricae. Acta Universitets Lundensis, Lunds Universit Årsskrift, 2: 1-14.

Trewin, N.H. and McNamara, K.J. 1995. Arthropods invade the land: trace fossils and palaeoenvironments of the Tumblagooda Sandstone (?late Silurian) of Kalbarri, Western Australia. Transactions of the Royal Society of Edinburgh: Earth Sciences, 85: 177-210.

Tripathi, S.C. 1995. Palaeontological and palaeoenvironmental studies of Bagh Group, M.P. Records of Geological Survey of India, 128 (6): 104-105.

Tripathi, S.C. 2006. Geology and Evolution of the Cretaceous Infratrappean Basins of Lower Narmada Valley, Western India., Journal of Geological Society of India, 67: 459-468.

Torell, O.M., 1870. Petrificata Suecana Formationis Cambricae. Acta Universitets Lundensis, Lunds Universit Årsskrift, 2: 1-14.

Uchman, A. 1995. Taxonomy and paleoecology of flysch trace fossils: The Marnoso-arenacea Formation and associated facies (Miocene, Northern Apennines, Italy). Beringeria, 15: 1-115.

Uchman, A. and Gazdzicki, A. 2006. New trace fossils from the La Meseta Formation (Eocene) of Seymour Island; Antarctica. Polish Polar Research, 27: 153-170.

Verma, K.K. 1971. On the occurrence of some trace fossils in the Bagh Beds of Amba Dongar area, Gujarat state. Indian Journal of Geoscience Association, 12: 37-40.

Verma, A. and Shukla, U.K. 2020. Hetrolithic Lower Rewa Sandstone of the Neoproterozoic Rewa Group, Vindhyan Basin, U.P., India: An example of tidal point bar. Precambrian Research, 350: 105932.

von Otto, E. 1854. Additamente zur Flora des Quadergebirges in Sachsen. Heft 2, 53 pp., Leizig (G. Mayer).

Vossler, S.M. and Pemberton, S.G. 1989. Ichnology and paleoecology of offshore siliciclastic deposits in the Cardium Formation (Turonian, Alberta, Canada). Palaeogeography Palaeoclimatology Palaeoecology, 74: 217-239.