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The early Cambrian (Series 2, Stage 3) burrows from the Nagaur Sandstone, Marwar Supergroup, Rajasthan, India: palaeoenvironmental and palaeoecological considerations

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In the present study, six well-preserved burrow forming ichnogenera such as *Planolites, Palaeophycus, Bergaueria, Monocraterion, Skolithos,* and *Treptichnus*, previously recorded from the early Cambrian Nagaur Group, have been critically examined to understand the behavior adopted by the burrow makers. These burrows help understand the interaction of the organisms with the past ecosystems. Transformation of burrow system from simple to complex (three-dimensional) forms are also elucidated. Their occurrences and associated depositional environments are discussed. No trilobite body fossil is found in the assemblage. Therefore, recorded six ichnogenera from the Nagaur Sandstone belong to the early Cambrian (Series 2, Stage 3). Their occurrence in the younger Phanerozoic successions and ranges are also discussed. Statistical analyses have been performed on the gathered dataset taking parameters of their occurrences and corresponding depositional settings which exhibit the trend of the diversity of these burrows and revealed a behavioral pattern of different burrow makers.

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INTRODUCTION

On the eve of the Cambrian Period, the biosphere, atmosphere, and hydrosphere experienced numerous changes in terms of the macroscopic, complex, and large body plan in organisms (Ediacaran biota), oceanic perturbations, and change in atmospheric oxygen (Xiao and Laflamme, 2009; Sahoo *et al*., 2012; Evans *et al*., 2018). These changes are directly or indirectly interrelated with the abundance of dissolved oxygen and organic carbon in the ocean water column along with increased nutrient supply (Evans *et al.*, 2018). After Gaskier glaciation (~580 Ma), the earth experienced an increase in the atmospheric oxygen level close to the present atmospheric level-PAL (Evans *et al*., 2018). But anoxic conditions prevailed in the ocean water column and atmospheric oxygen had experienced a downfall in the latest Ediacaran (~ 550 Ma) (Zhang *et al*., 2019). Consequently, existing Ediacaran biota started to vanish, and Earth experienced a novel change within the biosphere, atmosphere, and hydrosphere at the onset of the Cambrian Period, known as the Cambrian Explosion (Cloud 1948, p. 342; Conway-Morris, 1997).

During the late Ediacaran, the biosphere included diverse biota, animals, protists, algae, and fungi (Xiao and Laflamme, 2009; Pandey and Sharma, 2017; Xiao and Narbonne, 2020; Tang *et al.,* 2020) and extensive microbial mats were present in the ecosystem (Seilacher, 1999). Fossil records show numerous changes in bioturbation initiated during the Ediacaran-Cambrian boundary interval (Rogov *et al*., 2012; Herringshaw *et al*., 2017; Buatois *et al*., 2018; Cribb *et al*., 2019). Bioturbation implies how a living organism affects the substratum in which they live. The interplay of burrow makers with sediment and pore-water disturbed the sediment stratigraphy. Alteration in chemical reactions and sediment-water exchange together modify the physical properties of sediment such as grain size, porosity, and permeability. Thus, bioturbation is counted as a crucial factor involved in profound changes which characterized the Ediacaran-Cambrian boundary (Seilacher and Pflüger, 1994; Seilacher, 1999; Schiffbauer *et al*., 2016; Budd and Jensen, 2017). Bioturbation activities have a profound effect on the environment and thought to be a prime driver of biodiversity.

In the Precambrian time, bioturbation was rare and restricted in late Ediacaran (Rogov *et al.,* 2012; Cribb *et al.,* 2019). The original concept of the Agronomic Substrate Revolution (ASR) refers to the replacement of the Precambrian type substrates (mat-ground) (Seilacher, 1999; Mángano and Buatois, 2017) to the Phanerozoic type ones (mix-ground), thus change in substrate condition and bioturbation was one of the major causes of the Cambrian Explosion (Bottjer *et al*., 2000; Herringshaw *et al.,* 2017). Agronomic Revolution (AR) (Seilacher and Pflüger, 1994) is influenced by the existence of metazoans and burrowing habits (Mángano and Buatois, 2016; Pemberton *et al*., 2016).

Due to the advent of metazoans, some major changes noted across the Ediacaran-Cambrian boundary are the decline of stromatolites in number and size (Walter and Hayes, 1985), absence of microbial mat structures, extinction of the Ediacaran fossils (Xiao and Narbonne, 2020), initiation of skeletal fossils (Germs, 1972; Zhuravlev, 2012, 2015), and anoxic hydrosphere (Zhang *et al*., 2019). On the other hand, the Cambrian Information Revolution (CIR) included the presence of complex, innovative feeding mechanisms that permitted benthic creatures to effectively explore for nutrients on the ocean floor (Mángano and Buatois, 2017). The present study deals with some characteristic burrows recovered from the Nagaur Sandstone, Nagaur Group of the Marwar Supergroup, India to ascertain the existence of bioturbation and its influence on the biosphere.

The investigation demonstrates the different behavioral traits, palaeoecology, and diversification of the burrow system within the Cambrian and successive geological successions. Global occurrence and depositional environment in which they are found feeding habits, and behavior of trace makers are considered to reconstruct palaeoecology and their diversification. Pie charts and block diagrams are also made which elucidates the dominant depositional environment in which they survived.

GENERAL GEOLOGY AND AGE

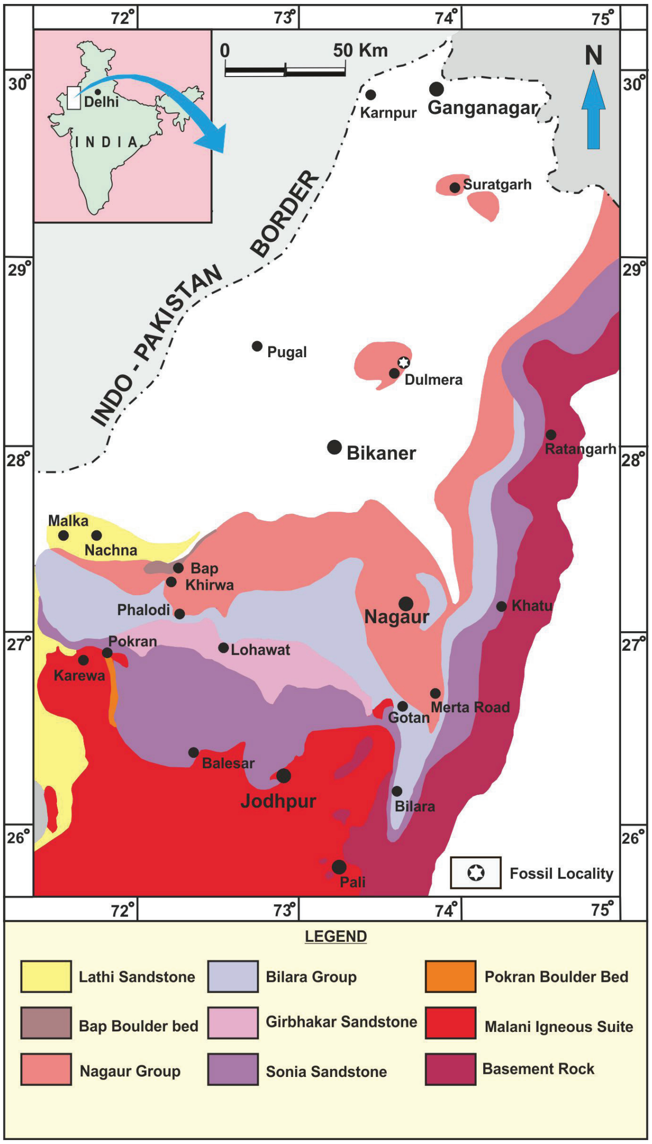

Fig. 1. Generalized geological map of the Marwar Supergroup showing the distribution of various litho-units and fossil locality (see star). (After Pareek, 1984).

The Marwar Supergroup (MSG) is one of the significant Ediacaran-Cambrian successions of peninsular India named after the Marwad region in Rajasthan. Sedimentary successions of the MSG are sitting above the Malani Igneous Suite (MIS). MSG, represented by thick argillo-arenaceous and carbonate facies in the Jodhpur-Khatu-Bikaner-Barmer, Nagaur-Phalodi areas of western Rajasthan, is about 1000 m thick (Pareek, 1984; Chauhan *et al*., 2004; Pandey and Bahadur, 2009) (Fig.1). Lithostratigraphic successions of the MSG are composed of conglomerate, sandstone, siltstone, shale, mudstone, dolostone, and limestone. Lithostratigraphically, MSG is subdivided into three groups and eight formations (Table-1). The Jodhpur and Nagaur groups are arenaceous to argillaceous, whereas the Bilara Group is calcareous in nature, which is sandwiched between these two groups (Pareek, 1984). The Jodhpur Group is subdivided into three formations; these are the Pokaran Boulder-Bed, Sonia Sandstone, and Girbhakar Sandstone. In the Pokaran area, Sonia Sandstone overlies the Pokaran Boulder Bed, while in rest of the basin; it is directly sitting on the Malani Igneous Suite (MIS). The Bilara Group unconformably overlies the Jodhpur Group, which represents the middle part of the MSG. It is composed of calcareous facies represented by dolostone, limestone, dolomitic limestone, siliceous dolomite, and minor shales. The Bilara Group is subdivided into three formations such as the Dhanapa Dolomite, the Gotan Limestone, and the Pondlo Dolomite. The Nagaur Group overlies the calcareous Bilara Group and represents the youngest group of the MSG. The Nagaur Group is subdivided into two formations namely the Nagaur Sandstone and the Tunklian Sandstone (Pareek, 1984). The Nagaur Sandstone is the lowermost litho-unit of the Nagaur Group composed of reddish to green color sandstone with intercalation of clay bands. The Tunklian Sandstone overlies it and represents the youngest formation of the MSG which is dominantly composed of medium to coarse-grained sandstone and pebbly sandstone.

The Nagaur Group revealed rich assemblages of the early Cambrian trace fossils mostly preserved in the Nagaur Sandstone. Trace fossils of the Cambrian age were first reported and described by Kumar and Pandey (2008, 2010). The discoveries of trace fossils from the Nagaur Sandstone opened a new window to understand the evolution and diversification of the complex metazoans. Subsequent palaeobiological studies established the age of the Nagaur Sandstone (Sharma and Pandey, 2011; Srivastava, 2012a, b; Singh *et al*., 2013; Singh *et al*., 2014; Pandey *et al*., 2014, Ahmad and Kumar, 2014). *Monomorphichnus multilineatus* and *Treptichnus pedum* have been studied in detail with regards to habitat, affinity, their behavior, and taphonomic

Table 1. Generalized lithostratigraphy of the Marwar Supergroup (after Pareek, 1984). 1. Xu *et al.* (2021); 2. Lan *et al.* (2020); 3. Wang *et al.* (2019); 4. George and Ray (2017); 5. McKenzie *et al.* (2011); 6. Gregory *et al.* (2009).

Age	Supergroup	Group	Formation	Radiometric age	Lithology
Permo-Carboniferus			Bap Boulder Bed		Subrounded, ellipsoidal cobbles and pebbles
			--------Unconformity--------		
Ediacaran to Middle Cambrian	**Marwar Supergroup**	Nagaur Group (75-500 m)	Tunklian Sandstone		Brick red sandstone, siltstone & red claystone
			Nagaur Sandstone	< 540 Ma (DZ LAICPMS)^{5}	Brick red sandstone, siltstone & red and green clay beds
		Bilara Group (100-300 m)	Pondlo Dolomite		Cherty dolomitic limestone, siliceous oolites and pesolites with subordinate claystone, siltstone at places
			Gotan Limestone	544 Ma (U-Pb)^{3}	Dark grey laminated limestone with bands of clay, chert and dolomite.
			Dhanapa Dolomite		Stromatoloitic limestone, dolomite, siliceous dolomitic limestone and laminated and nodular chert at the base
		Jodhpur Group (125-240 m)	Girbhakar Sandstone		Brick-red sandstone, siltstone and shale, pebbly to gritty near top
			Sonia Sandstone	651 Ma (U-Pb)^{1} < 616 Ma (U-Pb)^{2} 771 ± 05 Ma (Rb-Sr)^{4}	Maroon siltstone and shale, creamish sandstone with sedimentary structures. Banded chert-jasper, subordinate dolomite and sandstone
			Pokaran Boulder Bed		Subrounded, ellipsoidal cobbles, pebbles and sandstone
			--------Unconformity--------		
			Malani Igneous Suite	779-681 Ma^{6}	

biases (Sharma *et al*., 2018a, b). Singh *et al*. (2013) claimed the occurrence of articulated arthropod tergites but to date, no convincing trilobite body fossil has been recorded. Recent studies reveal that the Gotan Limestone is yielding terminal Ediacaran tubular calcareous fossil; and the overlying Pondlo Dolomite witness the Ediacaran-Cambrian boundary (Pandey *et al.,* 2019). Based on the overall palaeobiological assemblage, the Nagaur Sandstone is inferred to be deposited during Cambrian Period (Stage 2-3).

Limited geochronological data on the Marwar Supergroup are also available. The Malani Igneous Suite represents the basement of the MSG which is dated ~ 771 ± 5 Ma (Gregory *et al.,* 2009; Davis *et al.,* 2014). The lower part of the Jodhpur Group (the Sonia Sandstone) contains a tuff bed in the Chhoti Khatu area of the Jodhpur district which yielded Rb-Sr whole-rock isochron of 703 ± 40 Ma (George and Ray, 2017; George, 2020). They also suggested ∼100 Ma depositional hiatus between the Jodhpur and Bilara Groups. Xu *et al.* (2021) also dated the same unit of the Chhoti Khatu which yielded maximum age constrain as 651±18 Ma for the volcanics within the Sonia Sandstone and suggested about ~125 Ma hiatus between the end of Malani magmatism and subsequent Marwar deposition. Earlier, Wang *et al*. (2019) performed a study on Pan-African orogeny and dated siltstone unit within the Bilara carbonate which gave the youngest zircon (maximum age) estimation around 544 Ma, whereas, George and Ray (2017) suggested ∼570 Ma (late Ediacaran) depositional age for the Bilara Group based on Sr isotope stratigraphy. The age of the overlying Nagaur Sandstone is dated 540±1 Ma by the DZ-LAICPMS method, which is the maximum age estimation for the Nagaur Sandstone (Mckenzie *et al*., 2011). Based on carbon and oxygen isotope stratigraphy, Pandit *et al*. (2001), Mazumdar and Strauss (2006) suggested the Pc-C boundary within the Bilara Group. Later, Ansari *et al*. (2018) also demonstrated the presence of high amplitude negative carbon isotope excursion and probable Pc-C boundary within the Bilara Group. Based on the available palaeobiological investigations, the Jodhpur Group is considered to be of Ediacaran age whereas; the Nagaur Group is of the Cambrian in age. Therefore, the MSG represents the Ediacaran to Cambrian sedimentary succession.

MATERIALS AND METHODS

The present study is based on a large collection made over the years (2007-2015) from the Nagaur Sandstone exposed in Dulmera quarry, Bikaner district, Rajasthan, and subsequent laboratory investigations of trace fossils recorded earlier (Kumar and Pandey, 2008, 2010; Ahmad and Kumar, 2014; Sharma and Pandey, 2011; Sharma *et al.,* 2018a, b) (Fig. 2). Along with Dulmera specimens, global occurrences of all six ichnogenera have been reviewed in terms of their depositional environment in which they survived and thrived (see Table-2). Cluster analysis has been performed using CONISS software for identifying different zones (Grimm, 1987, 1990). The available parameters such as length, width, and frequency are used for dendrogram analyses. The dendrogram was created using software named SPSS version 22 package by ward method. It is used to assess the cohesiveness of the cluster formed and provide information about the appropriate numbers of the cluster to keep in a

Table 2. Distribution list of ichnogenera *Skolithos*, *Bergaueria*, *Palaeophycus*, *Monocraterion*, *Planolites* and *Treptichnus* across the globe with their respective different depositional environment.

S. No.	**Genus/species**	**Formation**	**Depositional Setting**	**Age**	
	References				
1	*Skolithos* isp.	Eriboll Formation, NW Scotland	Subtidal environment	Lower Cambrian	Davis *et al*. (2007)
2	*Skolithos* isp.	Pedroche Formation, Spain	Benthic conditions	Lower Cambrian	Gámez Vintaned *et al*. (2006)
3	*Skolithos linearis*	Candelaria Formation, Southern Brazil	No precise data	Cambrian - Ordovician	Aceñolaza and Nieva (2003)
4	*Skolithos* isp.	Wusonger Formation, Aksu, Southern Xinjiang, China	Tide Dominated	Cambrian	Liu *et al*. (2018)
5	*Skolithos* isp.	Raizama Formation, Brazil	Siliciclastic deposits	Cambrian	Santos *et al*. (2017)
6	*Skolithos* isp.	El Hank Formation, Morocco	Shallow water deposits	Middle to late Cambrian	Oukassou *et al*. (2017)
7	*Skolithis* isp.	Dibsiyah Formation, Saudi Arabia	Fluvial deposits	Cambrian	Keller *et al*. (2017)
8	*Skolithos* isp.	Fezouata Shale, Morocco	No precise data	Cambrian -Ordovician	Azizi *et al*. (2017)
9	*Skolithos* isp.	Kloftelv Formation, Ella, NE Greenland	Near shore marine setting	Lower Cambrian	Jensen *et al*. (2016)
10	*Skolithos* isp.	Ocieseki Sandstone Formation, Poland	No precise data	Cambrian	Stachacz, (2016)
11	*Skolithos* isp.	Kunzum La Formation, India	Marine deposits	Middle Cambrian	Parcha and Pandey (2016)
12	*Skolithos* isp.	Deh-Sufiyan Formation, Central alborz, Iran	Wave dominated carbonate ramp	Middle Cambrian	Bayet-Goll *et al*. (2016)
13	*Skolithos* isp.	Quyuk Formation, Victoria Island, Arctic Canada	Tide dominated conditions	Cambrian	Durbano *et al*. (2015)
14	*Skolithos* isp.	Zhoujieshan Formation, Qaidam Basin, NW China	Shallow water conditions	Cambrian	Al- Ajmi *et al*. (2015)
15	*Skolithos* isp.	Nagaur Group, Marwar Supergroup, India	Shallow water conditions	Lower Cambrian	Ahmad and Kumar (2014)
16	*Skolithos* isp.	Raizama Formation, Brazil	Fluvial coastal deposits	Cambrian	Santos *et al*. (2014)
17	*Skolithos* isp.	Dhaulagiri Formation, Lesser Himalaya, India	Shallow marine conditions	Cambrian	Tiwari *et al*. (2013)
18	*Skolithos* isp.	Araba Formation, Northeastern Egypt	Tidal environment	Cambrian	Elicki *et al*. (2013)
19	*Skolithos* isp.	Rhoscolyn Formation Holy Island, North Wales	Turbidite deposits	Lower Cambrian	Treagus *et al*. (2013)
20	*Skolithos* isp.	Burj and umm Ishrin Formation, Jordan	Shallow marine conditions	Cambrian	Hofmann *et al*. (2012)
21	*Skolithos* isp.	Gog Group, Western Canada	Tide Dominated	Lower Cambrian	Desjardins *et al*.(2012)
22	*Skolithos* isp.	Zhangxia Formation, Luoyang City, China	No precise data	Middle Cambrian	Qi *et al*. (2012)
23	*Skolithos* isp.	Wood canyon Formation, United states	Tidal environment	Lower Cambrian	Mata *et al*. (2012)
24	*Skolithos* isp.	Kunzum La Formation, India	No precise data	Cambrian	Parcha and Pandey (2011)
25	*Skolithos* isp.	Wood Canyon Formation, California	Fluvial environment	Cambrian	Kennedy and Droser (2011)
26	*Skolithos* isp.	Araba Formation, Egypt	Marginal-marine environment	Cambrian	Wanas, (2011)
27	*Skolithos* isp.	Bradore Formation, Quebec	Storm influenced	Lower Cambrian	Long and Yip (2009)
28	*Skolithos* isp.	Parahio Formation, NW Himalaya, India	Shoreface deposits	Cambrian	Singh, (2009)
29	*Skolithos* isp.	Tal Formation, India	No precise data	Lower Cambrian	Tiwari and Parcha (2006)
30	*Skolithos* isp.	Santa Rosita Formation, NW Argentina	Marine environment	Upper Cambrian	Mangano *et al*. (2005)
31	*Skolithos* isp.	Lower Tal Formation, India	No precise data	Lower Cambrian	Mathur and Srivastava (2005)
32	*Skolithos* isp.	Kunzum-La Formation, India	Deep to shallow shelf setting	Upper Cambrian	Parcha *et al*. (2005)
33	*Skolithos* isp.	Slottest Formation, North – East Greenland	No precise data	Lower Cambrian	Smith *et al*. (2004)
34	*Skolithos* isp.	Companario Formation, Argentina	Marine environment	Cambrian	Mangano and Buatois (2004)
35	*Skolithos* isp.	Hardyston Formation, USA	Fluvial to Marine	Lower Cambrian	Simpson *et al*. (2002)
36	*Skolithos* isp.	Chapel Island Formation, Newfoundland, Canada	No precise data	Lower Cambrian	Droser *et al*. (2002)
37	*Skolithos* isp.	Garbyang Formation, India	No precise data	Cambrian	Sudan and Sharma (2000)

38	*Skolithos* isp.	Kunzum-La Formation, India	Wave dominated shallow sea environment	Lower Cambrian	Parcha and Pandey (2011)
39	*Skolithos* isp.	Deadwood Formation, USA	Intertidal environment	Cambrian - Ordovician	Stanley and Feldmann (1998)
40	*Skolithos* isp.	Santa Rosita Formation, Argentina	Tide dominated	Upper Cambrian	Mangano *et al*. (1996)
41	*Skolithos* isp.	Timma Formation, Southern Israel	Marine environment	Lower Cambrian	Soudry and Weissbrod (1995)
42	*Skolithos* isp.	Bynguano Formation, New South Wales, Australia	No precise data	Cambrian - Ordovician	Droser *et al*. (1994)
43	*Skolithos ramosus*	Lintis Vale Formation, Central Australia	No precise data	Lower Cambrian	Walter *et al*. (1989)
44	*Skolithos linearis*	Bradroc Formation, Labrador	No precise data	Lower Cambrian	Pemberton and Frey (1984)
45	*Skolithos* isp.	Lodore Formation, NE Utah and NW Colorado	No precise data	Cambrian	Herr *et al*. (1982)
46	*Skolithos* isp.	Mt. Simon Formation, Wisconsin	Tidal deposition	Upper Cambrian	Driese *et al*. (1981)
47	*Bergaueria* isp.	Zabuk Formation, Turkey	Shallow –marine and fluvial environment	Lower Cambrian	Hosgor and Yilmaz (2018)
48	*Bergaueria* isp.	Antigua Formation, Antigua west indies	Benthic environment	Upper Oligocene	Donovan *et al*. (2017)
49	*Bergaueria* isp.	Pauji Formation, lake Maracibo, Venezuela	Shallow marine deposits	Eocene	Buatois *et al*. (2015)
50	*Bergaueria* isp.	Deh – Sufiyan Formation, Iran	Deep subtidal environment	Middle Cambrian	Bayet-Goll *et al*. (2016)
51	*Bergaueria* isp.	Ghelli Formation, Iran	Turbidite to marginal marine environment	Middle to late Ordovician	Bayet – Goll and Neto De Carvalho (2016)
52	*Bergaueria* isp.	Rio Mayer Formation, Austral Basin, Patagonia	Transgressive environment	Lower Cretaceous	Richiano, (2015)
53	*Bergaueria* isp.	Neyzar Formation, Iran	Shelf dominated environment	Upper Cretaceous	Bayet-Goll *et al*. (2015)
54	*Bergaueria* isp.	Pauji Formation, Western Venezuela	Shallow marine deposits	Eocene	Buatois *et al*. (2015)
55	*Bergaueria* isp.	Nagaur Sandstone, India	Shallow marine environment	Lower Cambrian	Ahmad and Kumar (2014)
56	*Bergaueria* isp.	Mussoorie Syncline, India	Subtidal environment	Lower Cambrian	Singh *et al*. (2014)
57	*Bergaueria* isp.	Rio Mayer Formation, Argentina	Shallow marine deposits	Lower Cretaceous	Richiano *et al.* (2013)
58	*Bergaueria* isp.	Burj Formation, Jordan	Shallow to marginal marine environment	Middle Cambrian	Hofmann *et al*. (2012)
59	*Bergaueria* isp.	Kalodongar Formation, Kachchh, India	Foreshore to offshore environment	Middle Jurassic	Joseph *et al*. (2012)
60	*Bergaueria* isp.	Rio Turbio Formation, Brazil	Tide dominated	Cambrian	Pearson *et al*. (2012)
61	*Bergaueria* isp.	Wood canyon Formation, USA	Lagoonal environment	Lower Cambrian	Mata *et al*. (2012)
62	*Bergaueria* isp.	Pimenterea Formation, Brazil	Marine environment	Devonian	Da silva *et al*. (2012)
63	*Bergaueria* isp.	Teresina Formation, Brazil	Marine environment	Permian	Lima and Netto (2012)
64	*Bergaueria* isp.	Kunzum La Formation, India	Marine Environment	Cambrian	Parcha and Pandey (2011)
65	*Bergaueria* isp.	Hawaz Formation, Western Libya	Shallow Marine Environment	Middle Ordovician	de Gibert *et al*. (2011)
66	*Bergaueria* isp.	Horlick Formation, Antartica	Nearshore to Intertidal Environment	Devonian	Bradshaw, (2010)
67	*Bergaueria* isp.	Muschelkalk Basin, Netherlands	Shallow Marine environment	Middle Triassic	Knaust, (2007)
68	*Bergaueria* isp.	Pedroche Formation, Spain	Benthic environment	Lower Cambrian	Gamez Vintanned *et al*. (2006)
69	*Bergaueria* isp.	Passaic Formation, New Jersey	Lacustrine Deposits	Upper Triassic	Metz, (2007)
70	*Bergaueria* isp.	Leetse Formation, Russia	Shallow Marine	Lower Ordovician	Ershova *et al*. (2006)
71	*Bergaueria hemispherica*	Santa Rosita Formation, Aregentina	Wave Dominated	Lower paleozoic	Mangano *et al*. (2005)
72	*Bergaueria* isp.	Campanario Formation, NW Argentina	Shallow Marine Environment	Middle Cambrian	Mangano and Buatois (2004)
73	*Bergaueria* isp.	Heweitan Formation, China	No precise data	Lower – Middle Triassic	Guocheng and Jiliang (1998)
74	*Bergaueria* isp.	Stirling range Formation, Australia	No precise data	Ediacaran	Cruse and Harris (1994)
75	*Bergaueria hemispherica*	Grant Land Formation, Canada	No precise data	Lower Cambrian	Hofmann *et al*. (1994)
76	*Bergaueria* isp.	Grant Rapids Formation, Alberta	Brackish – water setting	Lower Cretaceous	Beynon and Pemberton (1992)

77	*Bergaueria* isp.	Klabava Formation, Central Bohemia.	No precise data	Early Ordovician	Mikulas, (1992)
78	*Bergaueria* isp.	Aberystwyth Grits Formation, central wales	Marine Deposition	Lower Silurian	Crimes and Crossley (1991)
79	*Bergaueria* isp.	Cardium Formation, Canada	Storm Dominated	Upper Cretaceous	Vossler and Pemberton (1989)
80	*Bergaueria* isp.	Ironshore Formation, west Indies	No precise data	Pleistocene	Pemberton and Jones (1988)
81	*Bergaueria* isp.	Deep Spring Formation, USA	Shallow water conditions	Cambrian	Gevirtzman and Mount (1986)
82	*Palaeophycus herberti*	Khabour Formation Kurdistan, Iraq	Shallow marine Environment	Ordovician	Shingaly, (2016)
83	*Palaeophycus* isp.	Nsukka Formation, Southeastern Nigeria	Shallow Marine environment	Late Maastrichtian-Danian	Mode and Odmodu (2015)
84	*Palaeophycus* isp.	Kunzum La Formation, India	Deep to shallow shelf setting	Early Cambrian	Parcha and Pandey (2016)
85	*Palaeophycus* isp.	Deh – Sufiyan Formation, Iran	Wave dominated carbonate ramp	Middle Cambrian	Bayet Goll *et al*. (2016)
86	*Palaeophycus striatus*	Dhaulagiri Formation, India	Shallow marine	Early Cambrian	Singh *et al*. (2014b)
87	*Palaeophycus* isp.	Puncoviscana Formation, Argentina	No precise data	Early Cambrian	Acenolaza *et al*. (2005)
88	*Palaeophycus* isp.	Tyonek Formation, Alaska	Fluvial dominated	Miocene- Pliocene	Flores *et al.* (2000)
89	*Palaeophycus* isp.	Chadron Formation, South Dakota and Nebraska.	Lacustrine deposits	Eocene – Oligocene	Evans and Welzenbach (1998)
90	*Palaeophycus tubularis*	Muth Formation, India	No precise data	Devonian	Bhargava and Bassi (1988)
91	*Palaeophycus* isp.	Deep Spring Formation, Campito Formation, White Mountains, USA	Shallow water carbonate Shelf Environment	Early Cambrian	Gevirtzman and Mount (1986)
92	*Palaeophycus* isp	Funing Formation in the Jinhu Depression, Subei Basin, East China	Fluvial deposits	Palaeocene	Zhou *et al*. (2019)
93	*Monocraterion* isp.	Pitinga Formation, Brazil	Shallow Marine	Upper Silurian	Gonçalves *et al.* (2017)
94	*Monocraterion* isp.	Ballagan Formation	Fresh Water	Lower Carboniferous	Bennett *et al*. (2017)
95	*Monocraterion* isp.	Nayband Formation, Central Iran	Marine environment	Upper Triassic	Bayet – Goll and Daraei (2017)
96	*Monocraterion* isp.	Nagaur Group, western India	No precise data	Lower Cambrian	Ahmad and Kumar (2014)
97	*Monocraterion* isp.	Bhadasar Formation, India	Shallow Marine	Upper Jurassic	Desai and Saklani (2014)
98	*Monocraterion* isp.	Pochico Formation, Spain	Shallow Marine	Lower/Middle Ordovician	Rodriguez *et al*. (2014)
99	*Monocraterion* isp.	Kaladongar Formation, Kachchh, Western India	Mixed siliciclastic Carbonate sediments	Middle Jurassic	Joseph *et al*. (2012)
100	*Monocraterion tentaculatum*	Stairway Sandstone, Australia	Very Shallow Marine Environment	Ordovician	Davies *et al*. (2011)
100	*Monocraterion* isp.	Kunzum-La Formation, India	Shallow Marine environment	Cambrian	Parcha and Pandey (2011)
101	*Monocraterion* isp.	Gedaref Formation, Eastern Sudan	Deltaic environment	Middle to Upper Jurassic	Eisawi *et al*. (2011)
102	*Monocraterion* isp.	Horlick Formation, Antarctica	Intertidal environment	Devonian	Bradshaw (2010)
103	*Monocraterion* isp.	Eriboll Formation, Northwest Scotland	Sub-tidal environment	Lower Cambrian	Davis *et al*. (2009)
104	*Monocraterion* isp.	Anzaldo Formation, Bolivia	No precise data	Ordovician	Davies *et al*. (2007)
105	*Monocraterion* isp.	Kepintage Formation, Kalpin Area, Xijiang, China	Shallow water conditions	Silurian	Bai *et al*. (2008)
106	*Monocraterion* isp.	Pedroche Formation, Spain	Benthic Conditions	Lower Cambrian	Gamez Vintanned *et al*. (2006)
107	*Monocraterion* isp.	Salta Province, Argentina	Shallow water	Cambrian	Acenolaza (2005)
108	*Monocraterion* isp.	Wealden Strata, Southern England	Non-marine	Lower Cretaceous	Goldring *et al*. (2005)

109	*Monocraterion* isp.	Candelaria Formation, Argentina	No precise data	Cambrian – Ordovician	Acenolaza and Nieva (2003)
110	*Monocraterion* isp.	Balcarce Formation, Argentina	Tide dominated Environment	Cambrian – Ordovician	Poire *et al*. (2003)
111	*Monocraterion* isp.	Horlick Formation, Antarctica	Marine environment	Lower Devonian	Bradshaw *et al*. (2010)
112	*Monocraterion* isp.	Upper Liard Formation, Columbia	Marine environment	Middle Triassic	Zonneveld *et al*. (2001)
113	*Monocraterion* isp.	Shawangunk Formation, New Jersey	Marine Deposits	Silurian	Metz, (1998)
114	*Monocraterion* isp.	Breathitt Formation, Pennsylvanian	Marine environment	Lower Middle Carboniferous	Eble and Greb (1997)
115	*Monocraterion* isp.	Bynguano Formation, Australia	Shallow Marine environment	Early Paleozoic	Droser *et al*. (1994)
116	*Monocraterion* isp.	Grand Rapids Formation, Alberta	Brackish Water conditions	Lower Cretaceous	Benyon and Pemberton (1992)
117	*Monocraterion* isp.	Charmuria Formation, India	Lagoonal carbonate mud environment	Middle Proterozoic	Das and Rao (1992)
118	*Monocraterion* isp.	Bhander Group, India	Tidal flat environment	Precambrian	Chakrabarti, (1990)
119	*Monocraterion* isp.	Ratcliffe Brook Formation, Canada	Shallow water conditions	Lower Cambrian	Hofmann and Patel (1989)
120	*Monocraterion* isp.	Matapedia Formation, Canada	No precise data	Late Ordovician to early Silurian	Pickerill et al. (1988)
121	*Monocraterion* isp.	Price Formation, Central Appalachians	Estuarine deposits	Devonian – Carboniferous	Pickerill *et al*. (1988)
122	*Monocraterion* isp.	Takrouna Formation, Antarctica	No Precise data	Permian –Triassic	Zawiskie *et al*. (1983)
123	*Monocraterion* isp.	Escopus Formation, New York	No precise data	Lower Devonian	Marintsch and Flinks (1982)
124	*Monocraterion* isp.	Vryheid Formation, S Africa	Deltaic environment	Lower Permian	Stanistreet *et al*. (1980)
125	*Planolites* isp.	Telbesmi Formation, Turkey	Fluvial Environment	Cambrian	Demircan *et al*. (2018)
126	*Planolites* isp.	Wulongquing Formation, South China	Tidal flat Environment	Lower Cambrian	Ding *et al*. (2018)
127	*Planolites* isp.	Kunzum-La Formation, India	Deep to Shallow self setting	Lower Cambrian	Parcha and Pandey (2016)
128	*Planolites* isp.	Deh – Sufiyan Formation, Iran	Wave Dominated carbonate ramp	Middle Cambrian	Bayet- Goll *et al*. (2016)
129	*Planolites* isp.	Alum –Shale, SW Sweden	No precise data	Cambrian	Egenhoff *et al*. (2015)
130	*Planolites nicholsan*	Nagaur Group, India	Shallow water conditions	Lower Cambrian	Pandey *et al*. (2014)
131	*Planolites nicholsan*	Dhaulagiri Formation, India	Shallow Marine	Lower Cambrian	Tiwari *et al*. (2013)
	Planolites isp.	Chulaktau Formation, Kazakstan	No precise data	Lower Cambrian	Weber *et al*. (2013)
132	*Planolites* isp.	Dhaulagiri Formation, India	Shallow marine	Cambrian	Tiwari *et al*. (2013)
133	*Planolites* isp.	Jince and Buchadeva Formation, Czech Republic	Tide Dominated	Middle Cambrian	Mikulas *et al*. (2012)
134	*Planolites montanus*	Harkless Formation, USA	Marine Environment	Cambrian	Yeun Ahn *et al*. (2012)
135	*Planolites montanus*	Zhangxia Formation, Luoyang City, China	Sedimentary Environment	Middle Cambrian	Qi *et al*. (2012)
136	*Planolites serpens*	Sonia Formation, India	No precise data	Cambrian	Prasad and De (2012)
137	*Planolites vulgaris*	Wulongguing Formation	Shallow water conditions	Lower Cambrian	Weber *et al*. (2012)
138	*Planolites* isp.	Wusongger Formation, Xiajiang, China	Shallow water conditions	Lower Cambrian	Bai *et al*. (2012)
139	*Planolites* isp.	Kunzum-La Formation, India	Marine environment	Cambrian	Parcha and Pandey (2011)
140	*Planolites* isp.	Parahio Formation, India	Wave Dominated	Lower – Middle Cambrian	Singh, (2009)
141	*Planolites* isp.	Burges Shale Formation, Columbia	No precise data	Middle Cambrian	Johnston *et al*. (2009)
142	*Planolites montanus*	Eriboll Formation, northwest Scotland	Marine Environment	Lower Cambrian	Davies *et al*. (2009)
143	*Planolites* isp.	Pedroche Formation, Spain	Benthic conditions	Lower Cambrian	Gamez Vintaned *et al*. (2006)
144	*Planolites* isp.	Upper Tal Formation, India	No precise data	Lower Cambrian	Tiwari and Parcha (2006)
145	*Planolites* isp.	Santa Rosita Formation, Northwestern Argentina	Wave Dominated shallow sea	Upper Cambrian	Mangano *et al*. (2005)

146	*Planolites* isp.	Dhaulagiri Formation, India	No precise data	Lower Cambrian	Mathur and Srivastava (2005)
147	*Planolites* isp.	Companario Formation, Nortwestern Argentina	Intertidal environment	Middle Cambrian	Mangano and Buatois (2004)
148	*Planolites* isp.	Puncoviscana Formation, Northwest Argentina	No precise data	Cambrian	Acenolaza, (2004)
149	*Planolites* isp.	Puncoviscana Formation, Northwest Argentina	No precise data	Lower Cambrian	Acenolaza *et al*. (2003)
150	*Planolites* isp.	Balcarce Formation, Argentina	Tide Dominated	Cambrian - Ordovician	Poire *et al*. (2003)
151	*Planolites nicholsan*	Base of Jince Formation, Bohemia	No precise data	Middle Cambrian	Mikulas *et al*. (2002)
152	*Planolites* isp.	Kunzum-La Formation, India	Fluvial Environment	Lower Cambrian	Sudan *et al*. (2000)
153	*Planolites montanus*	Santa Rosita Formation, Northwest Argentina	Tide Dominated	Upper Cambrian-Early Ordovician	Mangano *et al*. (1996)
154	*Planolites nicholsan*	Levis Formation, Eastern Canada	Deep water	Middle Cambrian	Pickerill and Narbonne (1995)
155	*Planolites* isp.	Grant Land Formation, Northern Ellesmere	No precise data	Cambrian	Hofmann *et al*. (1994)
156	*Planolites* isp.	Bynguano Formation, New south wales, Australia	No precise data	Cambrian - Ordovician	Droser *et al*. (1994)
157	*Planolites* isp.	Bolw Me Down Brook Formation, Western Newfoundland, Canada	Marine Conditions	Lower Cambrian	Lindholm and Casey (1990)
158	*Planolites ballandus*	Lower El Kera Formation, Australia	No precise data	Cambrian	Walter *et al*. (1989)
159	*Planolites* isp.	Ratcliffe Brook Formation, Canada	Shallow water conditions	Lower Cambrian	Hofmann and Patel (1989)
160	*Planolites* isp.	Whirlwind Formation, West central USA	No precise data	Middle Cambrian	Kopaska – Merekel (1988)
161	*Planolites* isp.	Deep Spring Formation, USA	Shallow water conditions	Upper Cambrian	Gevirtzman and Mount (1986)
162	*Planolites* isp.	Hartshill Formation, Central England	Deep water	Cambrian	Brasier and Hewitt (1979)
163	*Treptichnus pedum*	Nagaur Group, Marwar Supergroup, India	Shallow water condition	Early Cambrian	Pandey *et al*. (2014)
164	*Treptichnus pedum*	Nagaur Sandstone, Marwar Supergroup, India	Shallow water condition	Early Cambrian	Srivastava, (2012a)
165	*Treptichnus pedum*	Tal Formation, Lesser Himalaya, India	Not mentioned	Early Cambrian	Singh *et al*. (2014a)
166	*Treptichnus pedum*	Lolab and Tal Formation, Himalaya, India	No Precise Data	Early Cambrian	Shah and Sudan, (1983); Singh and Rai, (1983)
167	*Treptichnus pedum*	Phe Formation, Zanskar region, Ladakh Himalaya, India	Shallow water condition	Cambrian	Parcha and Singh, (2010)
168	*Trychophycus; Phycodes*	Parahio section, Kunzum-la Formation, Spiti Valley, India	Shallow water condition	Early Cambrian	Parcha and Singh (2005)
169	*Treptichnus pedum*	Chapel Island Formation, Canada	Shallow water condition	Early Cambrian	Droser *et al*. (2002)
170	*Treptichnus pedum*	Chapel Island, GSSP, Fortune Head, Newfoundland, Canada	Not mentioned	Late Ediacaran to Early Cambrian	Gehling *et al*. (2001)
171	*Treptichnus pedum*	E Newfoundland, Canada	No Precise Data	?Furongian/?Early Ordovician,	Fillion and Pickerill, (1990)
172	*Treptichnus pedum*	Chapel Island Formation Newfoundland, Canada	No Precise Data	Late Ediacaran and Early Cambrian	Crimes and Anderson, 1985; Narbonne *et al.* (1987); Brasier *et al*. (1994); Landing, (1994)
173	*Treptichnus pedum*	Random Formation, SE Newfoundland, Canada	No Precise Data	Early Cambrian	Narbonne *et al*. (1987)
174	*Treptichnus pedum*	Boya Formation, Cassiar mountain, Canada	No Precise Data	Early Cambrian	Fritz, 1980; Fritz *et al*. (1983), Droser *et al*. (1999)
175	*Treptichnus pedum*	Lower Vampire Formation, Wernecke Mountains, Canada	No Precise Data	Early Cambrian	Nowlan *et al*. (1985) Droser, *et al*. 1999
176	*Treptichnus pedum*	Ingta Formation; Backbone Ranges Formation; Vampire Formation, Mackenzie Mountain, NW Canada	No Precise Data	Late Ediacaran and Early Cambrian	McNaughton and Narbonne, (1999)
177	cf. *Treptichnus pedum*	Guachos Formation, Argentina	Shallow water condition	Early Cambrian	Seilacher *et al*. (2005)

178	*Treptichnus pedum*	Balcare Formation, Buenos Aires Province, Argentina	No Precise Data	Cambrian	Regalia and Herrera, (1981)
179	*Treptichnus pedum*	Uratanna Formation, South Australia	Shallow water condition	Early Cambrian	Droser *et al.* (1999)
180	*Treptichnus pedum*	Parachilna Formation, Flinders Range, Australia	No Precise Data	Early Cambrian	Daily, (1972)
181	*Treptichnus pedum*	Arumbera Formation, Dinkey Creek Beds, Amadeus Basin, Australia	No Precise Data	Early Cambrian	Glaessner, (1969); Daily, (1972); Walter *et al.* (1989)
182	*Treptichnus pedum*	Urusis Formation, Southern Namibia	Not mentioned	Early Cambrian	Jensen and Runnegar, (2005)
183	*Treptichnus pedum*	Upper Nomtsas Formation, Spitskopf member and Urusis Formation of Nama Group, Namibia	Shallow water condition	Early Cambrian	Wilson *et al*. (2012)
184	*Treptichnus pedum*	Nama Group, Namibia	Not mentioned	Early Cambrian	Jensen *et al*. (2000)
185	*Treptichnus pedum*	Gross Aub Formation and Nomtas Formation, South Namibia	No Precise Data	Early Cambrian	Germs, (1972); Crimes and Germs (1982); Geyer and Uchman (1995)
186	*Treptichnus pedum*	Death Valley, USA	Not mentioned	Early Cambrian	Corsetti and Hagadorn, (2000)
187	*Treptichnus pedum*	Bright angle Shale, Grand Canyon, USA	No Precise Data	Early to Middle Cambrian	Seilacher, 1956; Eliot and Martin (1987)
188	*Treptichnus pedum*	Deep Spring formation, Campito Formation, White mountain, USA	No Precise Data	Early Cambrian	Alpert, (1977)
189	*Treptichnus pedum*	Gongwusu Formation, InnerMangolia, China	No Precise Data	Middle Ordovician	Li, (1993)
190	*Treptichnus pedum*	Kaili Formation, Guizhou Province, S China.	No Precise Data	Middle Cambrian	Yang, (1994); Wang and Wang, (2006)
191	*Treptichnus pedum*	Yu'anshan Formation, Yunnan Province, South China	No Precise Data	Early Cambrian	Zhu, (1997)
192	*Treptichnus pedum*	Wisniowka Formation, Holy cross mountain, Poland	No Precise Data	Furongian	Orlowski and Zylinska, (1996)
193	*Treptichnus pedum*	Ocieseki Formation, Holy cross mountain, Poland	No Precise Data	Early Cambrian	Orlowski,(1989)
194	*Treptichnus pedum*	Platysolenites zone, SE Poland	No Precise Data	Early Cambrian	Paczesna, (1985), (1986)
195	*Treptichnus pedum*	Detrital Beds, Sierra De Guadalupe, Spain	No Precise Data	Early Cambrian	Linan, (1984)
196	*Treptichnus pedum*	Vegadeo Limestone, Herreria Sandstone, Cantabrian Mountain, Spain	No Precise Data	Early Cambrian	Crimes *et al.* (1977); Baldwin, (1977)
197	*Treptichnus pedum*	Mickwitzia Sandstone, South Central Sweden	No Precise Data	Early Cambrian	Jensen, (1997)
198	*Treptichnus pedum*	Tornetrask Formation, Dividalen Group, North Swedens	No Precise Data	Late Ediacaran and Early Cambrian	Jensen and Grant, (1998)
199	*Treptichnus pedum*	Klipbak Formation, Vanrhynsdrop Group, South Africa	Shallow marine clastic setting	Early Cambrian	Buatois *et al*. (2013)
200	*Treptichnus pedum*	Neobolus beds, Salt Range, Pakistan	No Precise Data	Early Cambrian	Seilacher, (1955)
201	*Treptichnus pedum*	Puerto Blanco Formation, Sonora, Mexico	Not mentioned	Early Cambrian	Sour-Tovar, *et al*. (2007)
202	*Treptichnus pedum*	Melez Chorgrane Formation, Libya	No Precise Data	Early Cambrian Ordovician	Seilacher, (1969)
203	*Treptichnus pedum*	Rovno Formation, Ukriane	No Precise Data	Early Cambrian	Fedonkin, (1983), Palij, 1976
204	*Treptichnus pedum*	Breivik Formation, Finnmark, Norway	No Precise Data	Early Cambrian	Banks (1970), Foyn and Glaessner, (1979)
205	*Treptichnus pedum*	Lontova Formation, Estonia	No Precise Data	Early Cambrian	Palij *et al*. (1983)
206	*Treptichnus pedum*	Buen Formation, North Greenland	No Precise Data	Early Cambrian	Bryant and Pickerill, (1990)
207	*Treptichnus pedum*	Chapel Island and Random Formations, Canada	No precise data	Ediacaran-Cambrian Boundary	Palacios *et al*. (2017)
208	Treptichnus pedum	Nagaur Sandstone, Marwar Supergroup, India	No precise data	Cambrian (Series 2 Stage 4)	Sharma *et al*. (2018b)
209	*Treptichnus pedum*	Stáhpogieddi Formation Nama Group, Southern Africa.	Shallow Marine	Ediacaran–Cambrian	Jensen *et al*. (2018)
210	*Treptichnus pedum*	Wulongqing Formation, China	Intertidal environment	Cambrian(Series 2 Stage 4)	Ding, *et al*. (2018)

group. Specimens illustrated in the paper are deposited in the BSIP museum repository and can be accessed vide statement no 1569.

PALAEOENVIRONMENTAL AND PALAEO-ECOLOGICAL CONSIDERATIONS

All six ichnogenera *Planolites*, *Palaeophycus*, *Bergaueria*, *Monocraterion*, *Skolithos,* and *Treptichnus* representing bioturbation in the Nagaur Sandstone have been reviewed especially within the Cambrian and through the rest of the Phanerozoic Eon. (Fig. 3). Three ichnogenera *Skolithos*, *Planolites,* and *Treptichnus* have been considered for their occurrences and their environment of deposition within the Cambrian Period. Whereas, the rest of the three have been considered for study in all the successive periods within the Phanerozoic to see the changes and respective interrelation between occurrences and depositional realms in time and space.

Ichnogenus *Planolites* described from different stratigraphic successions of the Phanerozoic were consulted, but the present study is mainly confined to the occurrences of the Cambrian Period (Table 2). This ichnogenus is well reported from different parts of the world such as the Czech Republic, India, Iran, Pakistan, Turkey, South China, the USA, and others listed in Table-2. An attempt has been made to document the different depositional realms and their occurrences in time and space based on the published records along with the data generated from the Nagaur Group, India. Simple statistical analyses (Bar and pie diagrams) revealed an abundance of burrows in different geological ages. The investigation reveals that the burrowing habit was much more dominant in the lower Cambrian and gradually decreased in the middle and upper Cambrian (Fig. 4a-1). This tendency shows that the existence of organisms with capabilities to bulldoze sediments (burrow makers) such as crustaceans, coelenterates, arthropods, and different types of bilaterian was flourishing in the lower Cambrian as compared to the upper Cambrian. Further, the pie charts suggest different depositional realms which indicate that out of 39 occurrences, 3 were from sub-tidal, 2 from fluvial and 17 were from intertidal settings, and for remaining occurrences (17) no precise depositional environment was suggested.

Global occurrences of *Skolithos* (a vertical burrow) have been carefully reviewed from the whole Phanerozoic, but the present study is confined only to the Cambrian Period. Ichnogenus is well reported from different parts of the world such as Bhutan, Brazil, Canada, China, India, Pakistan, the USA, and other countries listed in Table 2. Statistical analyses suggested that the abundance of this burrow is different in the lower, middle, and upper Cambrian (Fig. 4a-2). Based on observations, the burrowing habit was much dominant in the lower Cambrian, and it gradually decreased in the middle and upper Cambrian. Same inferences have also been observed for *Planolites.* Further, the pie chart suggests different depositional realms which indicate that out of 47 occurrences 6 were from subtidal, 2 from fluvial, and a maximum of 23 were recorded from intertidal settings, whereas, rest of the 16 reports have no precise dataset for their depositional environment.

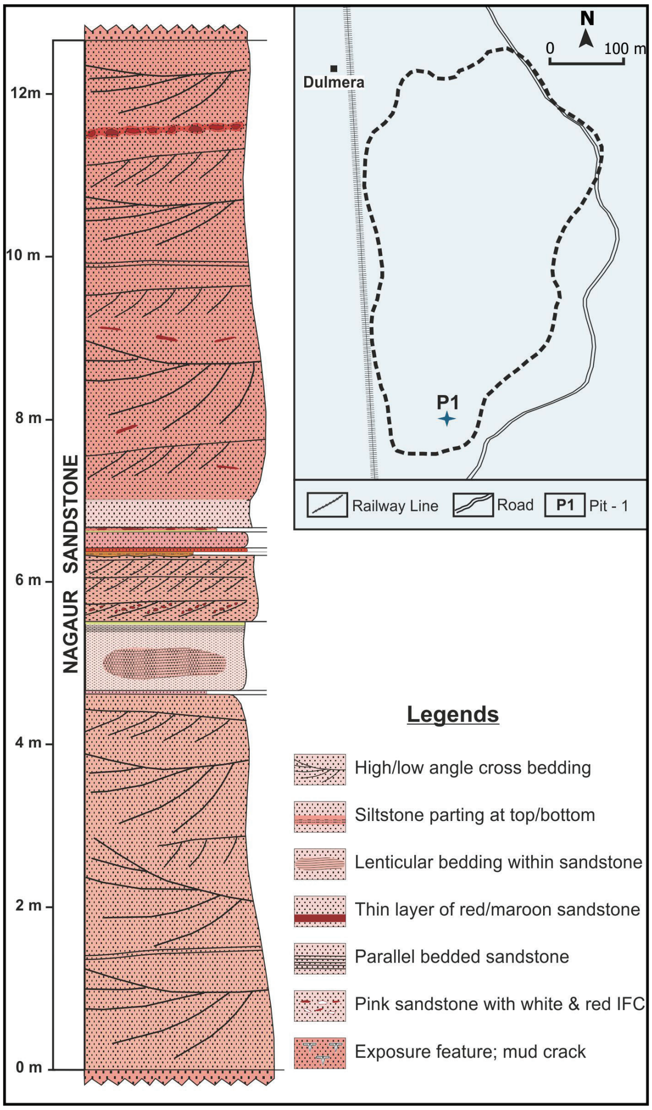

Fig. 2. (A) Generalized lithostratigraphic column of the Nagaur Sandstone based on the exposure in the Dulmera Quarry-Pit-1; (B) Extent of pit-1 of the Dulmera quarry exposures (after Sharma *et al.,* 2018 a,b).

Treptichnus is an ichnogenus that first appears at the Ediacaran-Cambrian boundary sections across the globe and abundantly preserved in different stratigraphic successions within the Cambrian Period. Recently, Sharma *et al*. (2018a) have performed an extensive study on the *Treptichnus pedum* recovered from the Nagaur Sandstone, Marwar Supergroup, India, and discussed plausible producers, mode of preservation; behavior, and palaeoecology. Reviewed datasets suggest its occurrences in different countries (Australia, Canada, India, South Africa, USA, and others listed in Table 2), in different stages of the Cambrian Period, and depositional settings. Statistical analyses suggest that the burrowing habit was much dominant in the early Cambrian compared to the successive middle and late Cambrian. Buatois *et al*., (2013) discussed the broad environmental tolerance for this species to survive, which lies between the upper shoreface to the foreshore tidal flat environment.

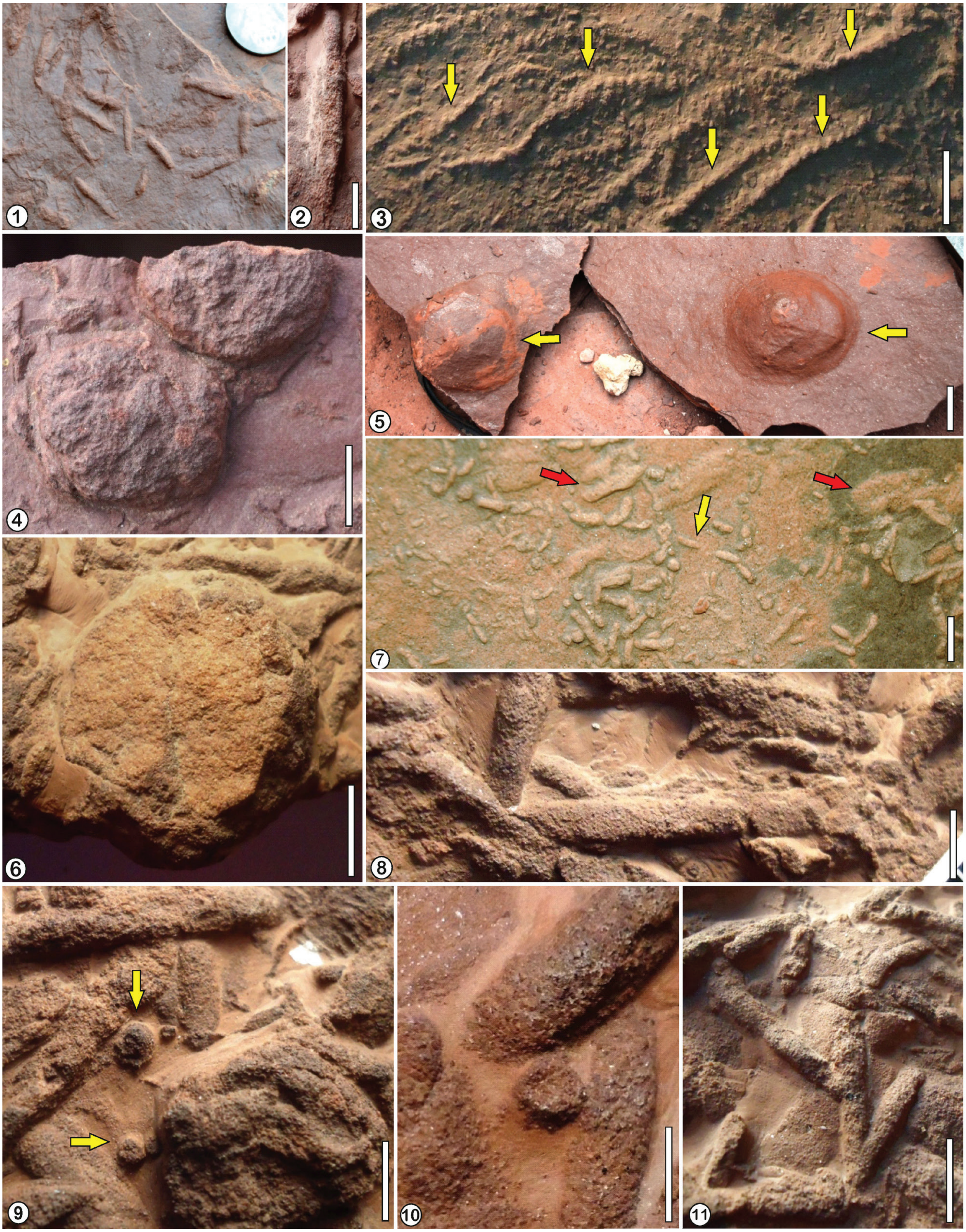

Fig 3. Outcrop photographs of studied six burrow forms reported from the Nagaur Sandstone, Marwar Supergroup. 1) *Planolites* isp. preserved on the sandstone as positive hyporelief; 2) Magnified view of *Planolites* isp.; 3) *Planolites annularis* showing well-preserved annulations (see yellow arrows); 4 and 6) *Bergaueria* isp. showing three-dimensional view of vertical burrow preserved as positive hyporelief; 5) *Monocraterion* preserved as positive hyporelief (see yellow arrows); 7) *Treptichnus pedum* small segmented horizontal burrows arranged in a linear/zig-zag pattern (see yellow arrow) red arrows showing associated probable *Rusophycus* isp.; 8 and 11) *Palaeophycus*; 9 and 10) *Skolithos* isp. preserved on the same surface along with *Palaeophycus*. (Scale =1 cm for all except, Fig. 1 which is 2.5 cm for coin and Fig. no. 2 which is 2 cm): (1, 2, 4, 5, 6 Field Photographs; **3** Museum specimen No. BSIP 41996; 7-11 Museum specimen No. BSIP 41857).

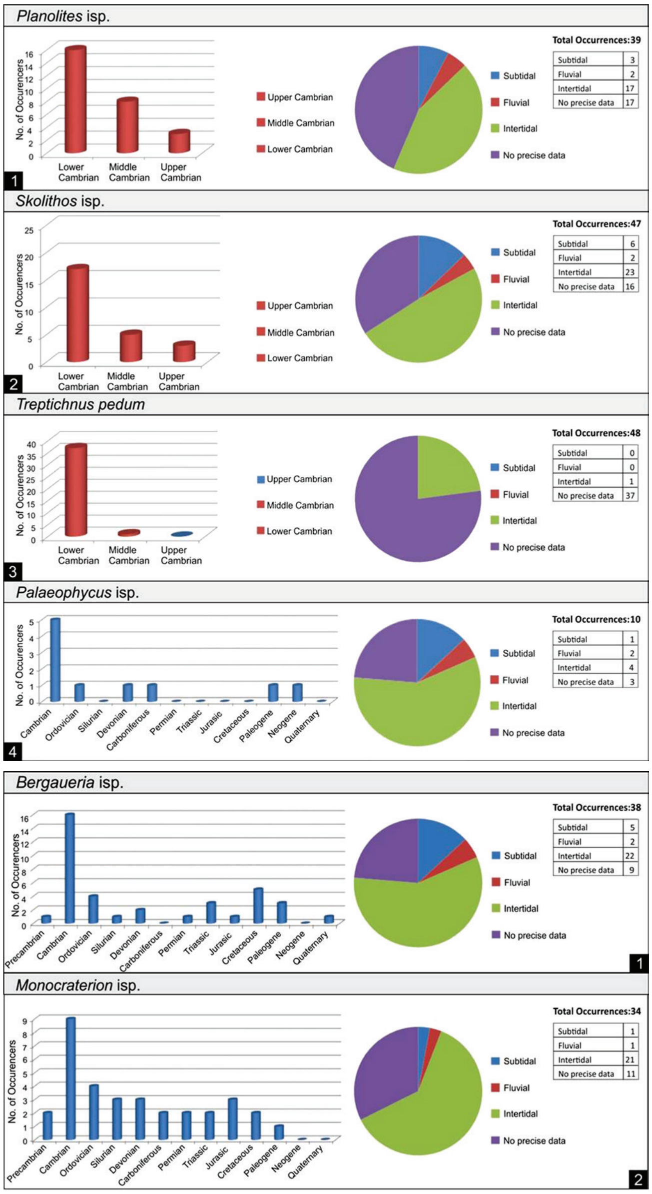

Fig. 4. a (1-4) and b (1-2). The composite figure of column graph and pie chart showing the occurrences of all six ichnogenera with their different geological ages and depositional environments.

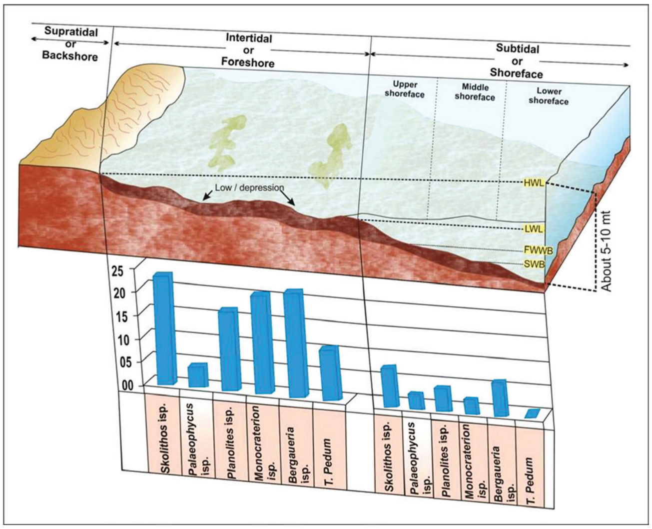

Fig. 5. A schematic diagram shows the distribution pattern of all six listed ichnogenera in two major depositional regimes: intertidal and subtidal. Significant abundance was seen in the intertidal depositional environment as compared to the subtidal.

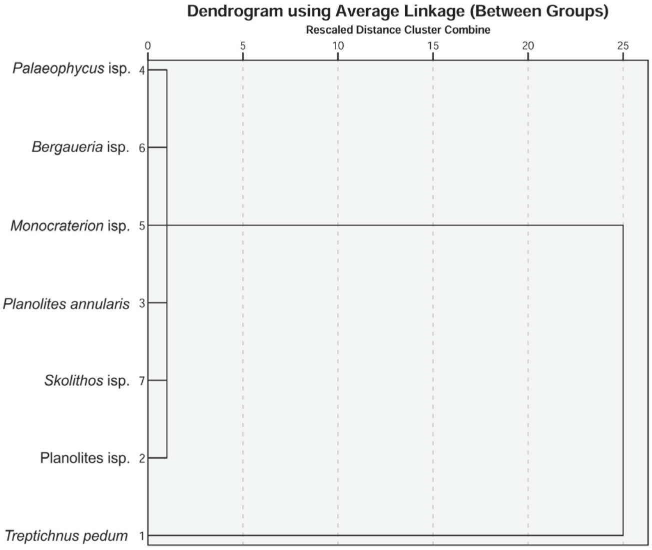

Fig. 6. Dendrogram analysis of all six ichnogenera using three parameters i.e., length, width, and relief inferred two groups of burrows system: one simple and second complex (three-dimensional).

Further, based on published occurrences, the pie chart suggests (Fig. 4a- 3) their distribution pattern in the different depositional realm: out of 47 occurrences none reported from subtidal, and fluvial environment and a maximum of 11 were recorded from intertidal settings, whereas, for the rest of 37 reports, no precise information was given for their depositional environment.

Palaeophycus is another globally distributed ichnogenus that also appeared for the first time in the Cambrian Period. Its global distribution pattern is given in Table 2. The occurrences and depositional environment of the ichnogenus *Palaeophycus* are reviewed for the entire Phanerozoic. Statistical analyses reveal the abundance of this burrow in the Cambrian Period, which became successively low in the Ordovician. The review suggested that *Palaeophycus* is rarely found in the successive younger ages in the Phanerozoic (Fig. 4a- 4). The graph shows the youngest occurrence found in the Neogene sediments. For the depositional setting, the pie chart suggests that out of 10 occurrences, maximum abundance was found in the intertidal settings *i.e.,* 4 compared to 1 in the subtidal regime and the rest of the 2 in the fluvial settings. For the rest of the 3 reports, no precise information was given for their depositional environment.

Bergaueria is also globally distributed in the number of lithostratigraphic successions in different countries such as Argentina, Brazil, India, Iran, Spain, and the USA (Table 2) in different ages. Statistical analyses suggest that maximum number of occurrences are noticed in the Cambrian Period which declines in the younger strata (Fig. 4b-1). The pie chart of the depositional setting indicates that out of 38 occurrences, 22 are from the intertidal, 5 from the subtidal, and 2 from the fluvial setting, and the rest of 9 reports has no precise information. Based on the global dataset, the youngest occurrence of the *Bergaueria* is reported from the Quaternary, whereas the oldest is from the Precambrian.

Monocraterion is a globally documented ichnofossil (Table 2). With the available dataset, a graph has been plotted for its occurrence in different periods of the Phanerozoic, which exhibits the maximum number of burrows are preserved in the Cambrian strata, which subsequently declined in the successive younger sediments. The pie chart represents their occurrence in a different depositional environment (Fig. 4b-2). Out of a total of 34 occurrences, 21 are from the intertidal succession, 1 from the subtidal, and 1 is from the fluvial setting whereas the rest of the 11 reports have no precise data are available for their depositional environment. The youngest occurrence is noted in the Paleogene sediments.

Studies on the above-mentioned six ichnogenera suggest that the process of burrow making was highly active in the lower Cambrian and gradually decreased in the successive younger stratigraphic column. After the mat ground environment of the Ediacaran age, mix-ground surface ocean prevailed in the intertidal setting where bioturbation activity was more prevalent than the subtidal regime (Fig. 5) as suggested by the overall review in the present study which also compliments study made by Buatois *et al*. (2013). It is also inferred that the bioturbation activity was prevailing in the suitable depth of around 1-10 meters in the ocean column. However, during adverse conditions, organisms adapted to suitable favorable environment settings of the subtidal regime.

CONCLUSIONS

1. Fossil burrows are the bonafide record of animal behavior and mode of lifestyle. The Nagaur Sandstone provides a legitimate example of evolution as it yields horizontal burrows such as *Palaeophycus* and *Planolites*, vertical burrows such as *Skolithos, Monocraterion, Bergaueria,* and complex three-dimensional burrow in the form of *Treptichnus*.
2. Ichnogenus *Treptichnus pedum* consists of burrows with a straight course with segments that regularly alternate in direction, whereas *Planolites*, *Skolithos, Monocraterion*, *Bergaueria*, *Palaeophycus* consist of the burrow with unidirectional (horizontal or perpendicular) to the bedding plane. Thus, the difference in behavioral traits of burrow makers can be observed.
3. The overlying ichnogenera such as *Planolites*, and *Treptichnus* suggest that the burrowing habit was dominant in the lower Cambrian which successively decreased in the middle and upper Cambrian. The abundance of sediment bulldozers (burrow makers) such as crustaceans, coelenterates, arthropods, and different types of bilaterian organisms flourished extensively in the Lower Cambrian.
4. Distribution pattern of ichnogenera *Monocraterion*, *Bergaueria,* and *Palaeophycus* suggest that the abundance of these burrows decreases in successive younger stratigraphic columns in the Phanerozoic. This may be due to the absence of mat/mixed ground, and/or the ecosystem must have witnessed with more complex biota.
5. Based on the published dataset, statistical analyses were performed and inferred that all six ichnofossils must have been preserved in two different major depositional settings i.e., intertidal, and subtidal. However, burrowing activity was more pronounced in the intertidal region as compared to the subtidal. The tendency of burrowing in the intertidal region may be due to the higher exposure of the ground surface for oxygenation conditions and nutrient availability.
7. Dendrogram analyses suggest that all the specimens belong to the two groups i.e., one group consists of *Palaeophycus, Bergaueria, Monocraterion, Planolites, Skolithos,* which exhibit a simple burrow system, while the second group consist of a lone member *Treptichnus* and represents the complex type of burrow system (three dimensional) (Fig. 6).

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