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Cambrian of the Himalaya and the Peninsular India-Biozonation, Depositional Environments and Biogeographic Provinces

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In the Indian Himalaya, the Cambrian sequences are exposed in the Lesser and Tethyan Himalayan zones (LHZ and THZ). In the LHZ, the Cambrian biozonation is available at four stratigraphic intervals, i.e., at ~542-535 Ma, ~524-513 Ma, ~516 Ma, and ~512 Ma. In the THZ, the Cambrian biozonation exists broadly at two stratigraphic intervals, i.e., ~514-505 Ma (in the Spiti region and partially in the Kashmir region) and ~505-498 Ma (in the Zaskar region and partially in the Kashmir region). The Indian Cambrian faunal elements share Gondwanan and peri-gondwanan affinities. The depositional environments of the Cambrian sediments of THZ and LHZ show a wide array of settings.

Cambrian of the Himalaya and the Peninsular India

In the Paleozoic succession of the Indian Himalaya, the Cambrian sequences, volumetrically form the most abundant rocks (Wadia, 1975; Brookfield, 1993). The Cambrian sequences occurs in two broad lithotectonic zones (i) the LHZ framed by the Main Boundary Thrust (MBT) in the south and the Main Central Thrust (MCT) in the north and, (ii) the THZ bounded by the Vaikrita Group rocks with tectonic / non-conformable contact with the Greater Himalayan Zone (GHZ) in the south and the Indus-Tsangpo Suture Zone (ITSZ) in the north.

The Cambrian sequences within each zone are classified according to the structural/topographic basin in which they occur. Myrow et al. (2009) suggested that the Greater Himalayan Zone (GHZ) also includes deformed Cambrian sedimentary rocks in its central part—a contention yet to be proved.

Rocks of the Cambrian age are also known from the craton of the peninsular part of the Indian plate i.e., the Bikaner-Nagaur region of the Rajasthan basin (Kumar and Pandey, 2008; 2010; Singh et al., 2014; Pandey et al., 2014; Ahmad and Kumar, 2014; Hughes, 2016; Sharma et al., 2018; Singh et al., 2019a). Fig. 1 illustrates locations of various Cambrian outcrops.

The Cambrian rocks in the THZ, from northwest to southeast, are exposed in the Kashmir, Zaskar-Spiti, and Kumaun-Garhwal regions (Hayden, 1904; Reed, 1910, 1934; Wadia, 1934; Kobayashi, 1934; Srikantia et al., 1980; Srikantia, 1981; Shah et al., 1980, 1988, 1991; Shah, 1982; 1993; Kumar and Singh, 1983; Kumar and Verma, 1987; Tiwari 1989, 1997; Whittington, 1986; Kacker and Srivastava, 1996; Jell and Hughes, 1997; Bhargava and Bassi, 1998; Myrow et al., 2006a, 2006b, 2016; 2018; Peng et al., 2009; Upadhyay and Parcha, 2012; Singh et al., 2014, 2015, 2016, 2017a, 2017b, Popov et al., 2015; Hughes, 2016; Gilbert et al., 2016; Hughes et al., 2018; Yin et al., 2018; Srikantia and Bhargava, 2018).

In LHZ, the Cambrian rocks are exposed in the core of the NW-SE trending doubly-plunging synclines, i.e., Nigali Dhar, Korgai, Mussoorie, and Garhwal (Azmi et al., 1981; Bhargava, 1984; Singh and Rai, 1983; Bhatt et al., 1983, 1985; Kumar et al., 1987; Brasier and Singh, 1987; Mathur and Joshi, 1989; Joshi et al., 1989; Prasad et al., 1990; Bhargava et al., 1998; Hughes et al., 2005; Jell and Hughes, 1997; Desai et al., 2010; Tarhan et al., 2014, Singh et al., 2015, 2017a, 2017b, 2019).

The Marwar Supergroup (~1200 m thick) in the Bikaner-Nagaur Basin (Peninsular India) incorporates the Neoproterozoic to early Cambrian sequence (Khan, 1971; Pareek, 1984; Kumar and Pandey, 2008, 2010; Srivastava, 2012; Singh et al., 2014; Pandey et al., 2014; Ahmad and Kumar, 2014; Sharma et al., 2018).

Beside these, the Cambrian sequence is also preserved in the Salt Range, Peshawar and Hazara regions in Pakistan Himalaya (Noetling; 1894; Redlich, 1899; Waagen, 1891; Schindewolf and Seilacher, 1955) and in Bhutan (Tangri and Pande, 1995; Tangri et al., 2003; Myrow et al., 2009, 2010; Hughes et al., 2011).

The present contribution provides a succinct updated summary of the Cambrian deposits of the Indian Himalaya and the peninsular India.

Development of the Cambrian Geology in the Himalaya and the Peninsular India

Pioneering monographic contributions to the Cambrian stratigraphy and palaeontology of Spiti were made by Hayden (1904), Reed (1910) and of Kashmir by Reed (1934). Subsequent,

Figure 1 (a) Different lithotectonic zones of the Himalaya, (b) Google-earth image showing the location of Cambrian successions in different part of the Himalaya and peninsular India.

contributions to the Cambrian lithostratigraphy, palaeontology and biostratigraphy between 1960 and 1995 came from the Geological Survey of India and the Jammu Universities (see Jell and Hughes, 1997; Hughes et al., 2005; Hughes, 2016 for synoptic review). These inputs pre-dated the modern global concepts; hence were revised by Jell and Hughes (1997) by re-naming the previously recorded faunal elements according to the latest development in the Cambrian palaeontology. Until 1997, the Himalayan Cambrian trilobite biostratigraphy remained inadequately understood due to poor (i) preservation of collected material, (ii) illustration of fossils, due to lack of sophisticated techniques and (iii) collections of fossils in remote terrains. In the last two decades, with improved communication in the Himalaya and advancement in the Cambrian palaeontology and biostratigraphy across the globe, the investigations in the Cambrian geology of the Himalaya received great incentive. The discovery of trilobites, small shelly fossils, brachiopods, and eocrinoids from the known and newly identified stratigraphic levels

have contributed to a better understanding of the Cambrian biostratigraphy and biozonation of the Tethyan Himalaya Zone (Peng et al., 2009; Singh et al., 2015, 2016, 2017a, 2017b, 2019a; Popov et al., 2015; Gilbert et al., 2016; Hughes, 2016; Yin et al., 2018; Kaur et al., 2019).

The Tal Group, which yielded the Cambrian fossils in 1980s, was originally described as “Tal Limestone” by Medlicott (1864) and “Tal beds” by Middlemiss (1887). They were considered a Jurassic-Cretaceous sequence (Medlicott, 1864; Middlemiss, 1887; Auden, 1934, 1937, Bhargava, 1972, 1976). The “Tal beds” were divided into lower and upper Tal by Middlemiss (1887). Auden (1934, 1937) also divided it in lower and upper (including the upper and almost entire lower parts of Middlemiss) parts. The “Tal Beds” unit was referred to as the Tal Formation by Bhargava (1972), which was upgraded to Tal Group and divided into three formations (Bhargava, 1979). Juyal (1979) described small shelly fossils (SSFs) from the Chert-phosphorite horizon of the base of the Tal Group in the Maldeoata section (Mussoorie syncline). Azmi et al. (1981) published additional materials as Cambro-Ordovician small shelly fossils (SSFs). Subsequently, in the entire LHZ, the early Cambrian fossils were recorded from the Tal Group (Bhargava, 1984; Brasier and Singh, 1987; Kumar et al., 1987; Bhatt et al., 1983, 1985; Bhargava et

al., 1998; Hughes et al., 2005).

Till recently, the Tal Group was assigned to early Cambrian, with an uncertain upper age limit (Hughes et al., 2005; Singh et al., 2019a). Discovery of Ordovician trace fossils constrains the upper age limit of the newly defined Tal Group to early Cambrian (~512 Ma), which with an angular unconformity is followed by early Ordovician Deona Formation (Singh et al., 2019b).

The discovery of Cambrian trace fossils from the Nagaur Sandstone of the Bikaner-Nagaur region (Rajasthan basin) extends the Cambrian marine deposits to the cratonic part of the Indian plate (Kumar and Pandey, 2008, 2010). Though several workers reported the Cambrian trace fossils, yet the precise age of the Nagaur Sandstone (within the Cambrian) remains disputed. Some workers assigned a Terreneuvian-Series 2 age, while others preferred latest part of Cambrian Series 2/ Stage 4 (see Hughes, 2016; Pandey et al., 2014; Singh et al., 2013, 2014; Sharma et al., 2018; Singh et al., 2019a).

Identification of the various Cambrian stages, refinements of the

biozonation and new discoveries from different sectors of the Himalaya and the peninsula have evoked keen interest the world over.

The Cambrian of the Himalaya and the Salt Range (Pakistan Himalaya) needs rigorous study to understand the genesis and distribution of the Cambrian rocks on the northern margin of the Indian plate.

Cambrian biozonation

Though the Cambrian period (~541 to 485 Ma) lasted for ~56 million years yet its biozonation in the Indian Himalaya is rather coarse and patchy. The Cambrian biozonation of the Himalaya and the Peninsular India is summarised in Table 1.

Biozonation in the Himalaya

The Cambrian deposits in the THZ are widely distributed and known from 21 valleys *i.e.*, Talar, Pohru, Lolab (in Kashmir), Niri-Tsarap Chu, Kurgiakh, Lunak, Karsha-Padam (in Zanskar), Baralacha

and Chandra (Lahaul), Ratang, Parahio, Sumna, Pin (in Spiti), Baspa, Gymthiang and Tidong (in Kinnaur), Chorgad and Nelang (Jadhganga), Girthi Ganga, Gori Ganga and Kali valleys (in Garhwal-Kumaun regions).

The Parahio valley (Spiti), the best studied section, preserves only the latest Cambrian Series 2 / Stage 4 to Wuliuan Stage (Miaolingian Series), *i.e.*, ~512-505 Ma interval; base of the succession is truncated by a fault and its top has suffered a pre-Ordovician erosion. Fossils younger than 505 Ma are known from a float in the Spiti region (Reed, 1910; Jell and Hughes, 1997). Recognition of ~512 to 505 Ma interval is based on four biozones and two levels of trilobites, small shelly and brachiopods fauna, *viz.*, *Haydenaspis parvatya* level (~511-510 Ma), (ii) *Oryctocephalus indicus* biozone (~509 Ma), *Kaotia prachina* biozone (~508 Ma), *Paramecephalus defossus* biozone (507 Ma), *Oryctocephalus salteri* biozone (506 Ma), and *Iranoleesia butes* level (505 Ma). *Agnostus spitiensis* and *Paranomocarella conjunctiva* (~502-500 Ma) are reported only from a float. Thus, the upper part of the Cambrian deposits of the Parahio valley remains undated. Since the *Redlichia noetlingi* (~512 Ma) in the Pin valley is also from a

Table 1. Biozonation of the Cambrian of the Himalaya and the Peninsular India.

float, thereby the lower age limit of the Cambrian deposits in the Parahio, Sumna and the Pin valleys also stay undated. A thick succession below the *O. indicus* biozone (~509 Ma) is well preserved in the Sumna and the Pin valleys where more work is required.

Biozonation in the Zaskar region is available for the ~505 Ma to ~498 Ma interval, which includes *Iranoleesiabutes* level, *Sudanomocarinasinindica*, *Lejopyge acantha* and *Proagnostus bulbos* biozones (Singh, 2008, 2011; Hughes et al., 2008; Peng et al., 2009; Hughes, 2016).

The biozonation in the Kashmir region has also been updated (Jell and Hughes, 1997; Peng et al., 2009). The available data enable recognition of five intervals: (i) ~*Paokannia magna* level (~514 Ma), (ii) *Redlichia noetlingi* biozone (~513-512 Ma), (iii) *Oryctocephalus salteri* (506 Ma), (iv) *Iranoleesia butes* level (505 Ma) and (v) *Blackwelderia-Cyclolorenzella* (~505 Ma to ~498 Ma) (Jell and Hughes, 1997; Peng et al., 2009).

From Kumaun region (THZ), Redlichid trilobite is known (Kacker and Srivastava, 1996; Myrow et al., 2018), whose proper identification is not possible due to its poor state of preservation.

In LHZ, the Cambrian biozonation is available at four intervals, i.e., at *Protohertzina anabarica* biozone (~542-535 Ma), an informal halkieriid-bearing biozone (~524-516 Ma), *Drepanopyge gopeni* level (~516 Ma), and *Redlichia noetlingi* biozone (~513-512 Ma). Rocks younger than ~512 Ma are not preserved due to pre-Ordovician erosion (Singh et al., 2019b).

So far rocks of the ~541 to ~514 Ma, that span the most important Ediacaran-Cambrian boundary, have not been identified in the THZ. Earlier reports of the Ediacaran-Cambrian fauna from the Kashmir region have been revised (Singh et al., 2019a), consequently, the lower age limit of the Cambrian sediments in THZ cannot be fixed. Presence or absence of these rocks has a direct bearing on the Cambrian palaeogeographic reconstruction of the THZ and LHZ.

Excellent Cambrian outcrops are available for studies in Lahaul, Kinnaur and Kumaun-Garhwal regions. However, extensive studies, similar to those in the Parahio valley (Spiti), have not been undertaken in these regions due to hostile terrain and paucity of Cambrian workers.

Biozonation in the Peninsular India

The Marwar Supergroup (~1200 m thick) in the Bikaner-Nagaur Basin represents a Neoproterozoic to early Cambrian sequence (Khan, 1971; Pareek, 1984). It is divisible into the Jodhpur, Bilara and Nagaur groups. The Nagaur Group in ascending order is divisible into the Nagaur Sandstone and the Tunklian Sandstone. Cambrian trace fossils representing *Cruziana* ichnofacies are known from the Nagaur Sandstone (Kumar and Pandey, 2008, 2010; Singh et al., 2014; Pandey et al., 2014; Sharma et al., 2018) together with articulated arthropod tergites (Singh et al., 2013) and serially repeated *Rusophycus* and intergrading *Cruziana* association (Chaubey and Singh, 2011). Abundant specimens of *Treptichnus pedum* made by priapulid like worms have been recorded from the Nagaur Sandstone (Srivastava, 2012), which are assigned to the Ediacaran-Cambrian boundary interval.

The age of the Nagaur Sandstone is unresolved and the proposed ages vary from (i) early Cambrian (Kumar and Pandey, 2008, 2010; Singh and Chaubey, 2011; Chaubey and Singh, 2011; Singh et al., 2013), (ii) Ediacaran-Cambrian boundary interval (~541 Ma) (Srivastava, 2012), (iii) Terreneuvian to Stage 2 (~526 to 521 Ma) (Pandey et al., 2014; Singh et al., 2014; Singh et al., 2019a), and (iv)

Cambrian Series 2, Stage 4 (~511 Ma) (Hughes, 2016; Sharma et al., 2018).

Biogeographic provinces

The Indian Cambrian faunal elements share Gondwanan and peri-Gondwanan affinities. As the lower part of the Cambrian (~541-515 Ma) has not been documented in the THZ, the affinity of this interval is disputable (Singh et al., 2019a). The *Paokannia magna* level (513-514 Ma) constitutes the oldest trilobite level recorded in Kashmir (THZ), which shows affinities with that of China. *Haydenaspis parvatya* level (~512-510 Ma) in Spiti contains faunal contents similar to those known from the North and the South China (Peng et al., 2009; Kaur et al., 2019). The faunal content of ~509-498 Ma (Miaolingian Series, =Middle Cambrian) is comparatively well documented in the Spiti and partially in the Kashmir and the Zaskar regions (Jell and Hughes, 1997; Peng et al., 2009; Singh, 2013; Singh et al., 2016; 2017a, 2017b; Hughes, 2016; Yin et al., 2018). The trilobite fauna of ~509-500 Ma interval including *Oryctocephalus indicus* biozone, *Kaotia prachina* biozone, *Paramocephalus defossus* biozone, *Oryctocephalus salteri* biozone, *Iranoleesia butes* level, *Sudanomocarinasin indica* biozone, *Lejopyge acantha* biozone and *Proagnostus bulbos* biozone shows close proximity to the North and the South China peri-gondwanan outboard terranes and to the Europe, Siberia, Kazakhstan, and North America. The ~497 to 485 Ma rocks were either not deposited or might have been eroded prior to the Cambro-Ordovician unconformity.

The Cambrian interval (~541-513) of the LHZ shows interesting paleobiogeography. The faunal content of LHZ of ~541-513 Ma interval shows close affinity to the peri-Gondwana block of the South China (Hughes et al., 2005) and Gondwanan blocks of Egypt and Jordan (Singh et al., 2019a). The arthropod/trilobite traces (~516-513 Ma), i.e., *Cruziana salomonis*, *Cruziana fasciculata*, *Rusophycus burjensis* and *Rusophycus dispar* from the LHZ (Singh et al., 2019a) show close affinity with those described from Jordan, Egypt, Turkey and Canada. A Gondwanan to peri-gondwanan affinities recorded from the Lower Quartzite-Shale members to Arkosic Sandstone Member (now a part of the Deona Formation) (Singh et al., 2019a, 2019b). It is attributed to a post-Lower Quartzite Member (Koti Dhaman Formation) tectonic activity that led to the shift of bioprovincialism.

Trilobite faunal elements in the LHZ are poorly known from two levels, i.e., (i) *Drepanopyge gopeni* level (~516 Ma) and (ii) *Redlichia noetlingi* (also including *Xela mathurjoshi*) (~512 Ma); their faunal contents show close affinity with that of South China (Hughes et al., 2005). The genus *Redlichia* (~512 Ma) is known from Kashmir, Spiti and Kumaun in THZ and the Nigalidhar syncline in LHZ (Kumar and Verma, 1987; Kacker and Srivastava, 1996; Kumar et al., 1987) and from a float in Spiti (Hayden, 1904; Reed, 1910). This genus is well known from the peri-gondwanan terrains mainly from Australia and South China. The genus *Xela* is well known from Australia.

Cambrian Depositional environment

Previous studies of the Cambrian sediments of the THZ and the LHZ show a wide array of depositional settings. Only the Cambrian of the Zaskar-Spiti regions (THZ) and the Nigalidhar-Mussoorie synclines (LHZ) have been studied for the depositional settings. Brookfield (1993), Myrow et al. (2003), Hughes et al. (2005); Peng et al. (2009) and Hughes, (2016) suggested that the Cambrian rocks

of the Tethyan and Lesser Himalayan zones were deposited in a continuous margin of the Indian plate, representing distal to proximal facies respectively. However, Bhargava and Bassi (1998), DeCelles et al. (2000), Bhargava, (2011), Bhargava et al. (2011), Martin (2017) and Singh et al. (2019a) favoured two different settings for these zones. Broadly, the so far studied intervals of the Cambrian period in THZ and LHZ are: ~512-505 (in Spiti), ~506-498 (in Zanskar) and ~541-512 Ma (in Nigalidhar and Mussoorie synclines).

The Cambrian sediments in the Zanskar-Spiti regions are classified into the Batal (?Proterozoic-?early Cambrian), Kunzam La (includes Parahio Member) (~512 Ma-505 Ma), Karsha (~506-501 Ma) and Kurgiakh (~501-498 Ma) formations. The Phe Formation in Zanskar includes the Batal as well as the Kunzam La formations.

The Batal Formation (?Proterozoic-?early Cambrian) in the Zanskar-Spiti region is interpreted to manifest peritidal, partly inter-tidal setting in somewhat poorly circulated basin (Srikantia and Bhargava, 1998; Bhargava and Bassi, 1998; Bhargava, 2008). The sedimentary structures in the Batal Formation are ripple marks, lenticular bedding and local graded bedding of limited thickness.

In the Udaipur region (Chamba syncline), the term Phe has been used for a sandstone/shale sequence, with carbonate beds towards the top (Draganits et al., 2008) and equated with the Batal and Kunzam La formations of the Spiti region, though no fossils have been reported. Draganits et al. (2008) interpreted as the “Phe Formation” of the Chamba represents gravity flow sediments of non-channelized mid-fan to outer-fan depositional environments. This formational unit requires an in-depth probe for interpreting the depositional settings in Zanskar-Spiti regions.

The Kunzam La Formation in the Zanskar-Spiti regions is variably interpreted in term of depositional settings. Some workers suggested that the Kunzam La Formation of the Spiti region was deposited in deeper-water euxinic (flysch facies) to shallow-water environments (Srikantia, 1981; Fuchs, 1982; Srikantia and Bhargava, 1983; Parcha et al., 2005). Bhargava et al. (1982, 1986) and Bhargava and Bassi (1998) suggested intertidal to subtidal environmental setting on the basis of sedimentary structures like cross-bedding, ripple marks, wavy ripples, lenticular bedding, low angle truncations, channel fill deposits of sands and syndepositional slumps. Garzanti et al. (1986) and Gaetani et al. (1986) considered the Kunzam La Formation is dominated by tidal-flat deposits. Myrow et al. (2006a, b) interpreted the Kunzam La Formation of the Zanskar-Spiti region to represent a siliciclastic deltaic deposit with switching deltaic lobes that contain numerous medium scale shoaling cycles ranging from storm-influenced offshore deposits to thick trough cross-bedded fluvial facies deposited under high rate of sedimentation. They identified wave-ripple laminations, hummocky cross-stratification (HCS), parallel lamination, parting lineation, symmetrical ripples, interference ripples, ball and pillow structures, pod and gutter casts in the Cambrian sediments of Zanskar-Spiti. Myrow et al. (2006a, 2006b) interpreted the carbonate beds to belong to transgressive systems tract (TST). Bhargava (2008, 2011) inferred low energy, mainly sub-tidal environment with mild bottom currents in basal part, storm influenced in middle part and inter-tidal to tidal flat. Virmani et al. (2015) studied the integrated ichnofabric and lithofacies and proposed a shallow marine wave dominated shoreface to offshore depositional setup in the Spiti region.

The Karsha and the Kurgiakh formations are recognised only in the Zanskar region and northern Lahaul (near Baralacha La). The

lower part (Thidsi Member) contains abundant stromatolites which have been interpreted to represent a subtidal environment with a low terrigenous influx (Nanda and Singh, 1977). The upper part (Teta Member) is interpreted to indicate increase in water depth, from peritidal to outer shelf environment, and therefore represents a deepening upwards sequence (Gaetani et al., 1985). Garzanti et al. (1986) and Gaetani et al. (1986) considered the transition from Karsha to Kurgiakh formations to represent a sequence of basinal turbidites developed as a response to tectonically induced subsidence associated with development of a foreland basin. Myrow et al. (2006b) suggested that the Karsha Formation records a transition from siliciclastic- to carbonate-dominated strata, representing a long-term decrease in supply of terrigenous detritus. Myrow et al. (2006b) interpreted deposition of the Kurgiakh Formation in a shallow-marine, storm-influenced environments. They interpreted that although the Karsha carbonate platform might have been drowned, it did not culminate in deep-sea flysch deposition.

The Cambrian sequences in the LHZ have been considered proximal equivalent of the THZ (Brookfield, 1993; Searle, 1986; Myrow et al., 2003, 2006a, 2006b; 2009; Hughes et al., 2005, 2018; Hughes, 2016). However, on the other hand, Saxena (1971), Bhargava et al. (1998, 2011), DeCelles et al. (2000); Bhargava (2008, 2011), Martin (2017), and Singh et al. (2019a) have suggested two different settings for the deposition of the Cambrian sequences in the LHZ and THZ.

The Tal Group in the LHZ shows variable conditions of deposition from the Garhwal syncline (very shallow water condition) to the Nigalidhar syncline (shallow-to deep water settings). Overall, most of the basal part of the Tal Group in these synclines begins with the phosphate bearing cherty succession (phosphorite in Mussoorie syncline), which was interpreted to have been deposited under restricted circulation over an uneven topography (Shanker, 1971; Bhargava et al., 1998) having an indirect connection with an open sea, which provided phosphate-rich upwelling currents (Bhargava, 2011). Mazumdar et al. (1999) interpreted that the chert-phosphorite in Mussoorie syncline record negative Ce and positive Eu anomalies. While Ce is an important paleoceanic redox indicator, Eu is rather immobile under normal diagenetic conditions. Hughes (2016) considered it to represent a condensed section. The black argillaceous shale overlying the chert successions is interpreted to represent euxinic condition. The arenaceous rocks of the Tal Group exhibit abundant trough and planar cross-bedding, flaser and lenticular beddings, rippled surfaces, reactivation surfaces and are interpreted to represent tidal-flat complex setting (Bhargava et al., 1998; Singh et al., 2019a). These rocks in the Mussoorie syncline based on clay mineral analysis are interpreted to have been deposited under shallow marine conditions (Ganesan, 1975). Singh et al. (2019a) based on sequence stratigraphy studies of the Koti Dhaman Formation (upper part of the Tal Group, Nigalidhar syncline) suggested that the Koti Dhaman Formation (from Lower Quartzite Member to Shale Member) represents compound dunes and sand sheets (sub-tidal), sand flat (tidal flat complex), migration of a sand-sheet complex in shallow sub-tidal environments during regression of a tide-dominated shoreline. The Shale Member was deposited in a mud-dominated tidal-flat setting. The mud flat facies of the Shale Member directly rests on the sand flat facies of the underlying para sequence—omitting the mixed flat facies, indicating a jump in facies, which is related to a break in sedimentation between the Shale Member and Lower Quartzite Member due to a possible forced-regressive event.

The Ediacaran-Cambrian boundary

In the Bikaner Basin (peninsular part), the abundance of *Treptichnus pedum* in the Nagaur Sandstone (Srivastava, 2012) indicates Ediacaran-Cambrian boundary interval in close proximity. In the LHZ, the presence of tuffites, glass and devitrified glass fragments in the Earthy Siltstone Member (Shaliyan Formation, Tal Group, Bhargava et al., 1998) were regarded to manifest Neoproterozoic Pan-African volcanism by Bhargava et al. (1998), who advocated placing of the Ediacaran-Cambrian boundary at the base of the overlying Chert Member, which has yielded rich small shelly fossils (SSFs) in the Mussoorie syncline and its fragmentary remains in the Nigalidhar Syncline (work under progress). This contention is further substantiated by the discovery of *Shaanxilithes ningqiangensis* (Tarhan et al., 2014) from the Early Siltstone Member.

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