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Recent Studies in the Proterozoic Sedimentary Belt of Himalaya

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This paper summarises the work done during last four years on stratigraphy and biostratigraphy of the Proterozoic sedimentary deposits of Himalaya. The Palaeoproterozoic and Mesoproterozoic sediments are more or less restricted to the Lesser Himalayan belt but the Neoproterozoic rocks are known from all the sectors of the Himalaya including Tethyan Himalaya. The Lesser Himalayan succession has been sudivided into Outer Lesser Himalayan Belt and Inner Lesser Himalayan Belt. Attempt has been made to correlate the stratigraphic units of these belts on the basis of lithology, structural setting, isotope geochemistry and biostratigraphy. The Pre-Ediacaran sediments of the Lesser Himalaya of NW and NE were studied for microbial life, stromatolites and isotope chemostratigraphy. Astrobiological implications were also considered for the microfossil community discovered from the chert deposits of the ancient rocks. Palaeoclimate for the Proterozoic era of the Himalaya is established for the first time.

Keyword: Proterozoic; Lesser Himalaya; Tethyan Himalaya; Stratigraphy; Biostratigraphy; Palaeoclimatology

Introduction

The Proterozoic sediments are well developed in the Himalaya which can be grouped into three different zones viz., Outer Lesser Himalayan Zone, Inner Lesser Himalayan Zone and Tethyan Zone. The Palaeoproterozoic and Mesoproterozoic sediments are dominantly developed in the Lesser Himalayan zone, while the Neoproterozoic sediments are present in almost all the zones. Since most of the sequences are devoid of diagnostic fossils and radiometric dates are not easily available, correlation of stratigraphic horizons exposed in widely separated regions which can be measured in hundreds of kilometres has always been very difficult and subjective. However, in the last few years, different workers attempted correlation using the available data including lithology, microfossils, carbon isotope data, detrital zircon dates, tectonic setting and stromatolites. Attempts were also made to suggest palaeoclimate for the Himalaya of the Proterozoic eon.

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Proterozoic Geology of Himalaya: N.C. Hughes and P.M. Myrow

Neoproterozoic rocks are known from all sectors of the Himalaya, but older Palaeoproterozoic to Mesoproterozoic are almost exclusively restricted to the Lesser Himalaya, occurring beyond it only in regions of extremely rapid uplift, such as Nanga Parbat (Whittington *et al*., 2000). Lying between the Main Boundary Thrust and the Main Central Thrust, the Lesser Himalaya is the southernmost of Himalayan lithotectonic belts to expose Proterozoic rocks within India, Nepal, and Bhutan (but not Pakistan, where the Salt Range exposes upper Neoproterozoic strata). In India, the Tons Thrust separates Lesser Himalaya into two parts: the southern "outer" Lesser Himalaya and the more northern "inner" Lesser Himalaya, the difference in depositional age of rocks immediately on either side of this thrust is modest. In the inner Lesser Himalaya these rocks are divided into a thick lower

Palaeoproterozoic succession, the youngest rocks of which were deposited at about 1.6 Ga, and an unconformably overlying thick succession of uppermost Mesoproterozoic and Neoproterozoic rocks, the oldest of which are ~ 1.1 Ga (McKenzie *et al*., 2011). The most significant break in depositional age thus occurs within the rocks of inner Lesser Himalaya, where early Neoproterozoic rocks of the Mandhali Formation unconformably overlie Palaeoproterozoic rocks of the Damtha Group and Gangolihat Dolomite (McKenzie *et al*., 2011).

Upper Mesoproterozoic and Neoproterozoic rocks of the outer Lesser Himalaya are mostly siliciclastic, and continue upwards into Cambrian strata. These strata resemble those of age-equivalent passive margin successions worldwide following the breakup of Rodinia (Myrow *et al*., 2019). Recent detrital zircon analysis of the Cryogenian, outer Lesser Himalayan Blaini Formation supports correlation of this diamictite with the Manjir Formation in the Tethyan Himalaya, and indicates that both the diamictites are likely Marinoan (ie ~635 Ma) in age (Myrow *et al*., 2019). The Tanakki Conglomerate of the Abbottabad area of Pakistan may also be a correlative (Hughes *et al*., 2019). Stratigraphically above this a marked contrast occurs between the carbonate-rich upper Neoproterozoic outer Lesser Himalaya Krol Group, and the siliciclastic Phe Formation of Tethyan Himalaya, and this facies difference is consistent with a northern deepening margin. In the Nigali Dhar syncline of the outer Lesser Himalaya, the Neoproterozoic succession is capped by beds containing spectacular specimens of the enigmatic late Ediacaran tubular organism *Shaanxilithes* (Tarhan *et al*., 2014). In Pakistan, where Himalayan deformation has been less severe, the Neoproterozoic can be traced further inboard, with the Sirban Formation, the Pakistani carbonate equivalent of the Krol Group, correlated with the evaporite-rich Salt Range Formation in the Salt Range of the Panjab (Hughes *et al*., 2019). A similar evaporitic succession, which is succeeded by Cambrian clastic rocks, lies immediately to the south of Salt Range thrust, the local expression of Himalayan Frontal thrust that marks the most inboard strata of the Himalaya. The similarity in stratigraphy across this fault, which separates the Himalaya from the Indian craton, discounts the recently proposed idea (Martin 2017) that the Himalayan Frontal thrust marks the boundary between the craton and a Himalayan Cambrian and Neoproterozoic terrane (Hughes *et al*., 2019).

Much of the sedimentary protolith of Greater Himalaya was Neoproterozoic in age, although at least some Cambrian protolith is known from the Everest region (Myrow *et al*., 2009). Upper Neoproterozoic rocks are also present at the base of Tethyan Himalayan succession, in part due to the fact that the South Tibetan Fault System cuts down stratigraphically to the west in the Indian Himalaya (Brookfield 1993; Myrow *et al*., 2009). In the Chamba Valley of Himachal Pradesh, sub-Cambrian strata includes several-thousand-meter-thick Neoproterozoic succession of sandstone and mudstone that includes an ~ 1000 m thick diamictite, the Manjir Formation, which rests between the underlying Chamba Formation and overlying Phe Formation, from which new detrital zircon profiles have recently been published (Myrow *et al*., 2019). Further to the east in Zanskar region, the Phe Formation passes vertically into the demonstrably Cambrian Parahio Formation (Hughes *et al*., 2018), the top of which marks the Kurgiakh tectonic event, the major pre-Himalayan event of the region (Myrow *et al*., 2016). Uplift of the outer Lesser Himalaya along the Tons Thrust at 16 Ma, and subsequent erosion of a thick Neoproterozic and Cambrian cover sequence (Colleps *et al*., 2018), played a pivotal role in the evolution of global seawater chemistry during the Cenozoic.

Lesser Himalayan Succession: V. C. Tewari

The Lesser Himalayan sedimentary succession is divided into two sedimentary belts. The older Deoban – Gangolihat – Buxa belt is characterized by Meso Neoproterozoic stromatolites and organic walled microfossils, whereas the younger Krol belt developed only in the western Himalaya has yielded Ediacaran metazoan in the Krol Formation and Lower Cambrian fossils in the Tal Formation. Many previous workers have indicated the correlation of Deoban Formation with the pre-Cryogenian-Ediacaran (Pre Ediacaran) successions in other parts of the Himalaya. Similarly, the correlation of Lower Vindhyan Semri Group of the central India with Deoban- Gangolihat- Buxa Group (Pre-Ediacaran) of the Lesser Himalaya is well known in the contemporary geological literature. Similarities exist in the stromatolites, microfossils and isotope stratigraphy.

Several publications on the Neoproterozoic – Early Cambrian NW Himalayan successions are currently in circulation indicating distinct carbon isotopic shift at the Krol-Tal contact marking the Proterozoic-Cambrian stratigraphic boundary. The emergence of multicellular Ediacaran life in the Upper Krol Formation is consistent with an increase in the atmospheric oxygen. The base of Ediacaran System in the Lesser Himalaya is established in the cap carbonate, the Blaini Formation overlying the glacial diamictites (Fig. 1). Many previous workers have noted that the pink cap carbonate of the Blaini Formation shows negative $\delta^{13}C$ value (-3‰ $_{PDB}$) and invariably correlate with the Marinoan glacial event. Tewari (2017) compared the existing carbon and oxygen isotope data base for the Eastern Gondwana land and South China, Siberia and North Africa and concluded that the Neoproterozoic-Early Cambrian stratigraphy shows great similarity in the nature and extent of the isotopic variation. The Ediacaran – Early Cambrian period must have been a time of continental extension and rifting in the Lesser Himalaya. Tewari and Bryanne (2019 in press) reported that the Ediacaran Krol carbonates of the Lesser Himalaya were deposited in the peritidal carbonate ramp-shelf depositional environment (Jiang *et al*., 2002). They envisaged continental extension leading to breakup of the Rodinia supercontinent and the creation of shallow epicontinental seas at low paleolatitudes in which Blaini-Krol-Tal Cryogenian diamictites Ediacaran carbonates (Fig. 1) and Tal phosphorite were deposited. The Neoproterozoic period is characterized by the major palaeoclimatic and palaeobiological evolution after the breakup of Rodinia Supercontinent and the assembly of eastern Gondwana land.

Proterozoic Geology of Northeastern Himalaya: V. C. Tewari

The Buxa Formation in Eastern Himalaya occurs as discrete patches in the Lesser Himalayan sequences. Stratigraphically it overlies the Daling Group and consists mainly of carbonates and quartzites. Dolomitic carbonates are characterized by stromatolites (Fig. 2) of early Riphean affinity. Microbiota in the cherty dolomite suggests Meso-Neoproterozoic age for these rocks. The dolostones are locally fossiliferous, as in the Rangit River section and near Tatapani in West Sikkim. Stromatolites have been reported from the upper levels of the dolostone beds (Tewari 2017a and references therein). The Lower Gondwana sediments were deposited during the early Permian marine transgression in different parts of the NW and NE Lesser Himalaya (Fig. 1). The signatures of Permo-Carboniferous global glaciations are preserved in the Tatapani area of the Rangit window in south Sikkim Lesser Himalaya. In the Darjeeling Himalaya, the Lower Permian Gondwana diamictite beds vary from 8-10 m in thickness and are exposed near the west side of Lish River. The diamictites are interbedded with 5-8 m thick fine grained sandstones. The Meso-Neoproterozoic stromatolites are very well preserved in the Buxa Dolomite Formation in Rangit River section near Tatapani and, along the road from Tatapani to Reshi and Namchi town to Mamley village. Highly diversified assemblage of *Colonnella columnaris*, *Conophyton garganicus*, *Kussiella kussiensis*, *Baicalia* sp., *Jurusania* sp., *Minjaria* sp., *Gymnosolen* sp., *Kalpanaella* sp., *Stratifera* sp., *Colleniella* sp., *Tungussia* sp., *Nucliella* sp. and *Acaciella* sp., are developed in the Eastern Himalaya (Tewari 2017). The chert bands associated with the stromatolites have yielded organic walled microfossils *Siphonophycus* sp., *Eomycetopsis* sp., *Obruchevella* sp., *Myxococcoides* sp. and *Oscillatoriopsis* sp. (Tewari 2017a). The Laser Raman Spectroscopy and Confocal Laser Scanning Microscopy have shown that these bacteria are biogenic and can be considered proxies for the extraterrestrial life on other planets (Tewari 2017b). Some workers of astrobiology have speculated that stromatolites, microbial mats and bacteria like features are likely to be found on the Martian surface. A stromatolite park may be developed at Tatapani to preserve these evidences of early life. It is inferred that sedimentation ceased by the time early Cryogenian glaciations ended, so that there is no record of rocks of Cryogenian and Ediacaran period in this region. On the other hand, the Permian glaciation is well represented in the Tatapani in the form of Rangeet Boulder Beds of Gondwana time. These glacial diamictites indicate cooler Permian climate for the eastern Himalayan basin.

The Buxa dolomite of Rangit Tectonic Window in Sikkim and Deoban dolomite around Chakrata in NW Himalaya display diverse organic walled

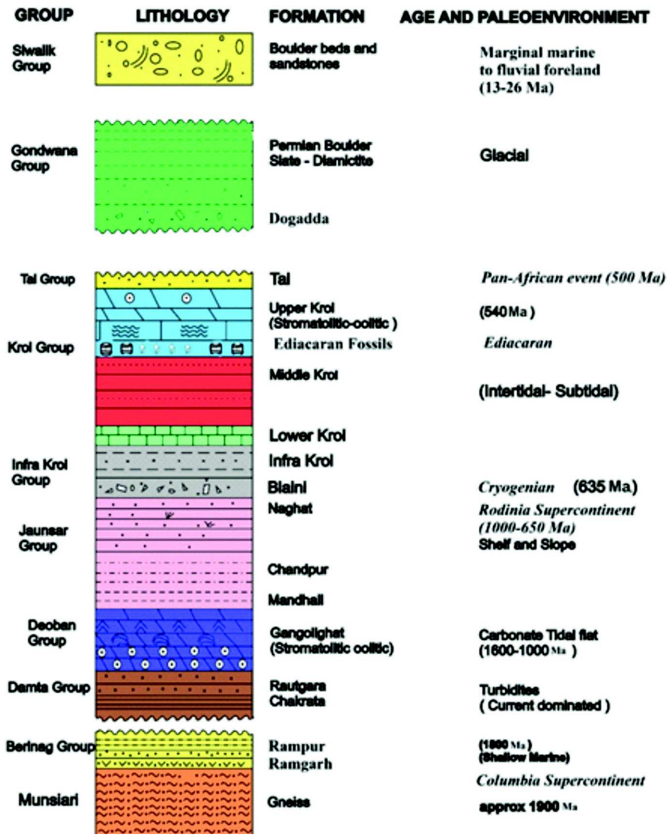

Fig. 1: Generalised lithostratigraphy, depositional environment and major palaeoclimatic events of the Lesser Himalaya, based on the authors own work and recent review (Tewari 2017, 2019. in press)

Fig. 2: *Acaciella* Walter stromatolitic buildup developed in the Buxa Dolomite, Rangeet Window , Sikkim Lesser Himalaya

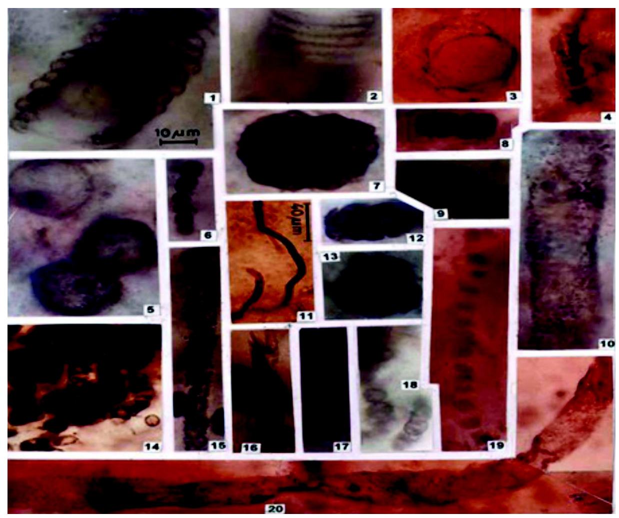

Fig. 3: Filamentous and coccoidal cyanobacterial community preserved in the Meso- Neoproterozoic Deoban cherts of the Chakrata area, Dehradun, Garhwal Lesser Himalaya

microscopic fossils (Fig. 3). There is a close similarity in the microfossil assemblages from the two regions. Several morphotypes exhibiting varying stages of cellular degradation have been recorded. Similarity with other Proterozoic microfossils and to modern marine microorganisms is striking.Tewari suggested that the Lesser Himalayan sea in the northwest and northeast was interconnected and also connected to the Vindhyan sea and the sedimentary environment favoured luxuriant microbial growth in the photic zone of a shallow intertidal to subtidal carbonate platform.

Tiwari contends that the astrobiology has now emerged as a distinct field of research where the possibility of extra-terrestrial life (Tewari 2017b and references therein) is looked into. The Precambrian prokaryotes on Earth are used as analogues for such studies (Tewari 2017b, 2019).

Proterozoic Plaeoclimate in the Himalaya: O. N. Bhargava and B. P. Singh

Palaeoproterozoic

Based on the identification of a paleosol over the ~1866 Ma Jeori Wangtu Gneissic Basement Complex (Bhargava *et al.*, 2011) and below the ~1800 Ma Rampur Group (=Berinag, Saryu Valley, Dharagad, Shumal), a warm and humid climate in a waterlogged terrain of gentle relief is suggested. Widespread development of basic volcanics (tholeiite) at the base of the Rampur Group is expected to have released enormous amount of CO_2, which warmed the climate around 1800 Ma.

Extensive development and appreciable thickness of the Manikaran Formation and its equivalents over the entire length of the Himalaya indicates that a network of big rivers existed that transported huge amount of sediments to the shallow marine basin all over the Himalaya. Existence of a major network of rivers suggests a fairly humid/pluvial and warm climate post ca.1800 Ma volcanism assuming the sediment released from the source directly reached the sink.

Bhargava and Singh are of the opinion that there is no record of sediments for the 1800-1600 Ma interval in the Himalaya.

Mesoproterozoic

Stromatolitic carbonate sequences represent the Mesoproterozoic rocks in the Himalaya. Apart from the rocks of the Shali Group (Srikantia and Sharma 1976), not much of the lithostratigraphic details are available for other carbonate sequences. Bhargava and Singh (2019) therefore based all palaeoclimatic interpretations for the Himlayan rocks on the data available for the Shali Group only. All carbonate sequences in Himachal commence with a red-grey coloured quartz arenite designated as the Khaira/Ropri (Srikantia and Sharma 1976), which indicates warm and humid climate. Next in order of superposition are Khatpul Formation composed of red shale followed by stromatolitic dolostone with local karstic breccia containing clasts of dolomite. The Sorghawari Formation consists of pink limestone in lower part and grey in upper part with stunted stromatolites. The Tattapani Formation is made up of grey stromatolitic dolomite with black shale in upper part. The presence of red shale and sandstone in these sequences and profuse development of stromatolite indicates dominantly warm climate. The Sorghawari Formation is succeeded by Makri Formation which is made up of grey, green, purple shale and interbedded limestone, dolostone and quartz arenite. The Parnali Formation contains stromatolitic dolostone with intermittent bands of quartz arenite and karstic breccia having clasts of limestone, shale and sandstone. The Bandla Formation encloses green and purple shale, siltstone, marly limestone, quartz arenite and green brecciated rock. Increase of finer clastics (shale and siltstone) contents at the cost of carbonates indicate onset of pluvial environment. Karstic breccia together with stromatolites in the Parnali and Bandla formations indicate lowering of the base level and return to a drier phase. These may also be taken as indicators of sedimentological hiatuses within the Mesoproterozoic sequences.

Neoproterozoic

Bhargava and Singh summarized their work on the Neoproterzoic *Tonian* (1000-720 Ma) succession represented by the tholeiitic Darla (Tattapani) Volcanics. These are overlain by the (i) Basantpur Formation (=Mandhali Formation) consisting of river borne, clast supported conglomerate at the base followed up by the stromatolitic Naldera-Kakarhatti-Kunihar limestone, shale, siltstone and siliciclastic-carbonates (ii) the Chaosa Formation (=Chandpur Formation) constituting shale, siltstone, fine grained sandstone and (iii) Sanjauli Formation (=Nagthat Formation) including greyish to red sandstone, shale and conglomerate lenses and sporadic halite casts. The Sanjauli and Nagthat (Jaunsar Group) formations enclose 860 Ma detrital mica (Bhargava and Frank 2008), which makes the Sanjauli Formation younger than 860 Ma. The TattapaniVolcanics below the Basantpur Formation, thus should be much older. The Tattapani volcanism, possibly signify initiation of breaking up of the Rodinia, which caused degassing leading to warmer climate. The cobble bed in the Basantpur Formation indicates the presence of turbulent rivers (humid/pluvial climate), while the stromatolitic limestone buildup suggests a warm climate.Clastic rocks in the Chaosa Formation reflect a humid climate that helped extensive weathering, erosion and transportation of arenites to the depositional basin and caused termination of the stromatolitic carbonate formation. Red sediments of the Sanjauli Formation suggest warm and humid climate, with intermittent aridity as indicated by occasional halite casts and mud cracks. Thus, from Tattapani Volcanics to the Sanjauli Formation, the Tonian in the Himalaya began with warm climate, upgraded to the pluvial phase and was punctuated with arid climatic events towards the end phase.The *Cryogenian* in the Himalaya is represented by the Blaini (=Manjir diamictites in western Himachal Pradesh and Nakechu Formation in Bhutan) constituting two levels of diamictites, overlain by flesh coloured cap carbonate, which in turn is succeeded by the black shale, siltstone of the Infra Krol

Formation. The Blaini Formation represents glaciations. Since its equivalent is not identified in the southern peninsula, it is unlikely to represent continental glaciations. These authors interpreted these rocks as products of valley glaciers, which merged with the sea. The palaeogeographic reconstruction of the Indian Plate suggests its location within 5° north of the equator (Scotese, 2009). During this time, the glaciation is attributed to higher altitude similar to the contemporary active glaciers in the Himalaya. The *Ediacaran* is represented through the Krol Group and Earthy Siltstone Member of the Tal Group, suggesting that the Krol-Tal contact is not the PC-C boundary. The Krol Group consisting of stromatolitic carbonates, indicates a warm climate. The red shale of the Krol B indicates introduction of humidity, with occasional aridity as suggested by the presence of gypsum. Introduction of the clastics in Krol D suggests somewhat humid condition. There was development of karstic condition during the Krol C and D, suggesting lowering of the base level (Jiang *et al*., 2002, 2003), which may indicate onset of a drier climate. The Krol Group, sandwiched between the 635 Ma Blaini and the upper most Ediacaran Earthy Siltstone Member should represent a 635-542 Ma interval. The red shale of the Krol B extensively developed between Solan and Nainital, not only indicates a reducing environment, but also acts as a time plane. The arid climate in this time interval is represented by the salt beds in Salt Range, which are 600 Ma old. The Mandi Salt, associated with stromatolitic red dolostone of the Ropri Formation, referred above, may also be of the same age range of ~600 Ma. Thus, the 600 Ma time period seems to represent a warm-arid episode not only in the Himalaya but also in the Salt Range. Warm conditions with phases of humidity prevailed during the Earthy Siltstone time (Shaliyan Formation, Tal Group).

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