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An overview of Rodinia–Gondwana Supercontinents, India – Asia Collision, emergence of Himalaya and Paleobiogeography of the eastern Tethys in Indian Subcontinent, South Asia

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ABSTRACT

The existence of Rodinia Supercontinent during Meso-Neoproterozoic and its subsequent breakup and reassembly as Gondwana Supercontinent is a widely accepted hypothesis in geological history of the Earth. The breakup of the Rodinia resulted in formation of rift basins and passive continental margins around 650 Ma. Major palaeoclimatic events like Neoproterozoic global glaciation (Snowball Earth) followed by global warming have been recorded from different continents including Indian Lesser Himalaya (Blaini - Krol Cryogenian - Ediacaran Period). 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 (Blainian). The pink cap carbonate of the Blaini Formation shows negative $\delta^{13}C$ value (-3‰ PDB) and invariably correlate with the Marinoan glacial event. Large continents of Gondwanaland Supercontinent South America, Africa, India, Australia and Antarctica were located over the South Polar region and global equatorial to polar oceanic circulation was blocked and may have been the main cause of glaciation. Paleogeographically Carboniferous–Permian diamictite, coal beds and plant fossil bearing Gondwana outcrops are found in South Sikkim and Arunachal Lesser Himalaya of Northeast India. The Late Paleocene - Middle Eocene Tethyan foraminiferal - algal carbonate biofacies are well developed after Late Cretaceous - Paleogene mass extinction event in the eastern Tethys, Meghalaya, east India. These Tethyan benthic orthophragmine foraminiferal – algal limestones were deposited in the passive continental margin setting of a shallow marine carbonate shelf in eastern Tethys and Standard Benthic Zones (SBZ) of the Alpine - Adriatic western Tethys are recorded from Meghalaya. The Cretaceous - Tertiary boundary is well marked in these basins by biotic mass extinction. Late Cretaceous mega ammonoid fossils and Sauropod dinosaur bones are abundantly found in the Maastrichtian Mahadeo Formation. The present $\delta^{13}C$ and $\delta^{18}O$ isotope data is comparable with the marine values of the limestone The Umlatodoh Limestone contains foraminiferal taxa of early Ilerdian and Middle Eocene (early Lutetian) age. The Indo-Myanmar Orogenic Belt (IMOB) represents the eastern suture of Indian plate and it was formed due to the collision of the Indian plate with the Myanmar plate. The Naga-Manipur ophiolites have been assigned to range in age from Upper Cretaceous to Eocene on the basis of faunal assemblages (radiolarian, planktonic foraminefera) in the olistolithic blocks of pelagic limestone and cherts. Pan Indian Pre and Post India - Asia Collision, emergence of Himalaya and Paleogeography of the Indian Subcontinent has been discussed in South Asia.

Keywords: Gondwana supercontinent, Himalaya, paleobiogeography, south Asia

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INTRODUCTION

Rodinia Supercontinent and Cryogenian - Ediacaran Period in Indian Subcontinent, Eastern Gondwana: Overview and Chemostratigraphy

The reconstruction of Rodinia supercontinent and the paleo-position of India (Vindhyan basin and Lesser Himalaya) is shown in Figure 1. Lesser Himalayan Meso-Neoproterozoic sedimentary basins (Inner Deoban-Gangolihat belt and outer Blaini-Krol belt) must have existed within the Rodinia. Early Earth possibly witnessed its most extreme climatic fluctuations during the late Neoproterozoic between 750-550 Ma. (Figs. 1, 2, 3). Palaeoglaciers even reached the equator around 635 Ma covering the whole earth. Evidences from Australia, South China, India, Oman, polar regions of Europe (Svalbard and Oslo), Canada (Newfoundland), USA (Death Valley near California), Africa, Antarctica, South America (Brazil and Argentina), suggest that there might have been three or more palaeoglacial events during this 200 Ma interval. The global decline of Meso-Neoproterozoic stromatolites, biotic extinctions and discovery of new Ediacaran life after cold climate have been bio, chrono, and chemostratigraphically correlated. Carbon isotopic excursions from all the continents have given the identical results and strongly support the existence of a supercontinent Rodinia during 1100-650 Ma. (Tewari and Sial, 2007; Tewari, 2007, 2010, 2012).The basement of the Lesser Himalaya is not exposed. However, sedimentological evolution of the Lesser Himalaya appears to have initiated with the late Palaeoproterozoic rifting event (1800 Ma, Figs. 2, 3).

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 (Singh, 1980; Tewari, 1984, 1989, 2007, 2009, 2010, 2012; Tewari and Qureshy, 1985; Figs. 1, 2). 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 (Valdiya, 2002; Shukla et al., 1987, 2006). Attempts were also made to suggest palaeoclimate for the Himalaya of the Proterozoic Eon (Tewari, 1984, 1989, 1992, 2001, 2007, 2010, 2012; Hughes et al., 2019; Myrow et al., 2019). Upper Mesoproterozoic and Neoproterozoic rocks of the outer Lesser Himalaya are mostly siliciclastic, and continue upwards into Cambrian strata (Fig. 3). The compression related tectonic readjustment in the Lesser Himalayan region is suggested during the Neoproterozoic Lesser Himalayan Orogeny which caused deformation of deeper facies equivalents of the Lesser Himalayan sediments and changed them to the Lesser Himalayan crystallines, granite magmatism (1000-900 Ma), uplift of the Lesser Himalayan sequences and southward shift of the Lesser Himalayan basin where in the outer Lesser Himalayan Jaunsar - Blaini-Krol-Tal cycle was deposited in a relatively confined basin (Figs. 2, 3).

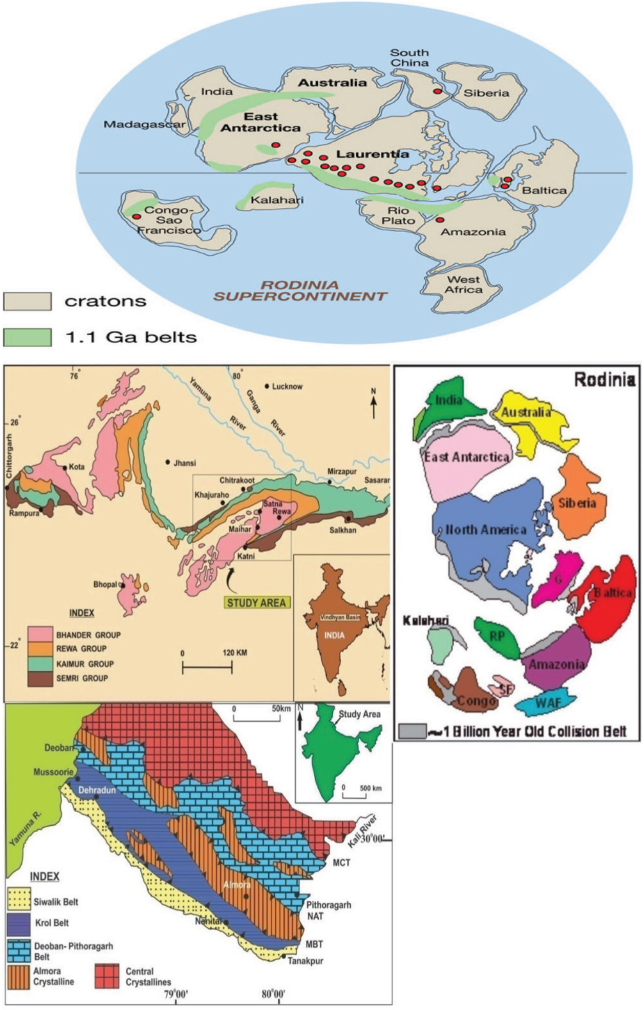

Fig. 1: One billion year old Rodinia collision belt, paleoposition of India and Vindhyan and Lesser Himalayan basins (modified after Tewari, 1998, 2010b).

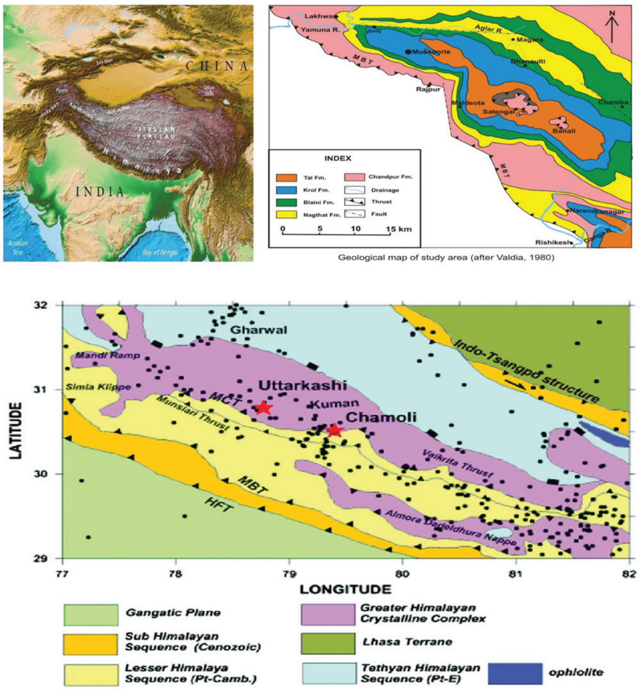

Fig. 2: Location and geological map of the Uttarakhand Lesser Himalaya (Kumaun–Garhwal) ,Northern India (modified after Valdiya, 1980), showing the Neoproterozoic (Ediacaran)–Lower Cambrian Blaini-Krol-Tal formations in Mussoorie syncline (above), located between two tectonic units (below) Main Boundary Thrust (MBT) and Main Central Thrust (MCT).

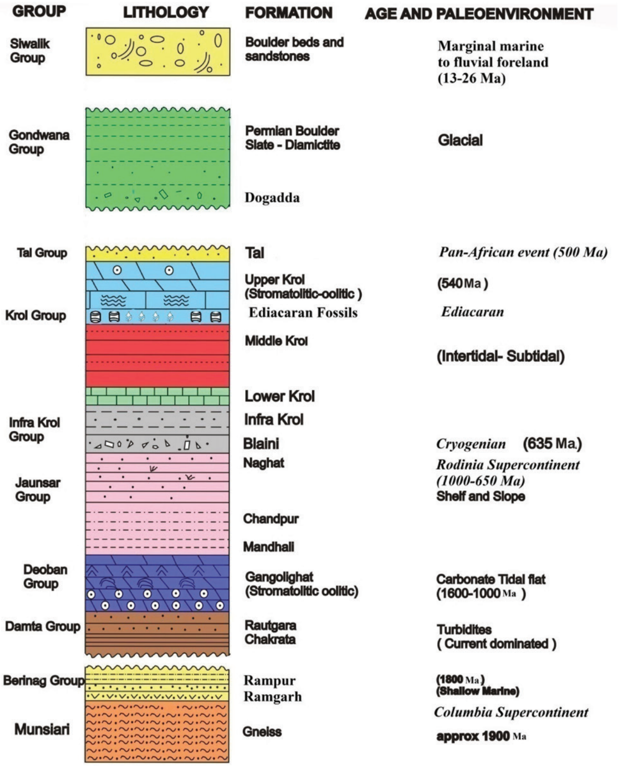

Fig. 3: Pan Indian Pre-collision (Paleo-Proterozoic-Cryogenian-Ediacaran) and Gondwana stratigraphy of the Lesser Himalaya, India after (Tewari, 2022).

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 (i.e. ~635 Ma) in age (Myrow et al., 2019). The Tanakki Conglomerate of the Abbottabad area of Pakistan may also be a correlative (Tewari, 1984, 2010; Fig. 4; Tewari and Sial, 2007; 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 Korgai -Nigali Dhar syncline of the outer Lesser Himalaya in Himachal Himalaya, the Ediacaran succession with Vendotaenids (*Krolotaenia gnilovskayi*) is capped by beds containing late Ediacaran tubular organism Shaanxilithes and Lower Cambrian taxa of stromatolites (Tewari, 1989, 1992, 1993, 2004, 2007, 2012). The Neoproterozoic can be traced further as Abbotabad Formation in Pakistani carbonate equivalent of the Krol Group, correlated with the evaporite-rich Salt Range Formation in the Salt Range of the Panjab (Tewari, 1984, 1989, 2010, 2017; Hughes et al., 2019). Much of the sedimentary rocks of Higher 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 (Kumar et al., 2020; Myrow et al., 2019; Bhargava and Singh, 2022). 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 in Kumar et al., 2020).

Lesser Himalayan Sedimentary Basins: Pre- Ediacaran, Ediacaran and Precambrian – Cambrian boundary Sedimentation and evolution of unicellular to multicellular life

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 and metaphytes in the Krol Formation and Lower Cambrian fossils and stromatolites in the Tal Formation (Tewari, 1984, 1989, 1993, 1998, 2009, 2010). Many previous workers have indicated the correlation of Deoban Formation with the pre-Cryogenian-Ediacaran (Pre Ediacaran successions) in other parts of the Himalaya (Shukla et al., 1987, 2006; Tewari, 2011). 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 (Valdiya, 1980; Tewari, 1984, 1989, 2003, 2007, 2010a,b, 2011, 2012; Tewari and Sial, 2007; Tewari and Tucker, 2011; Schopf et al., 2008; Kumar et al., 2020 and references therein; Fig. 1).

The Ediacaran – Early Cambrian period must have been a time of continental extension and rifting in the Lesser Himalaya. Tewari (2010) and Jiang et al. (2002) reported that the Ediacaran Krol carbonates of the Lesser Himalaya were deposited in the peritidal carbonate ramp-shelf depositional environment. 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 and Tal phosphorite were deposited (Figs. 2, 3, 4). 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. The Vindhyan sediments of the Peninsular India were also part of Rodinia Supercontinent and are equivalent of the Lesser Himalayan sediments (Fig. 1). Vindhyan sediments have been broadly assigned early Mesoproterozoic to early Neoproterozoic age (Tewari, 1989; Srivastava and Tewari, 2011; Prasad and Ashar, 2021). The Blaini - Krol - Tal succession of the Lesser Himalaya is now well established as Cryogenian to Lower Cambrian age based on micro and mega fossils like organic walled microfossils, acanthomorphic acritarchs, stromatolites, small shelly fossils,

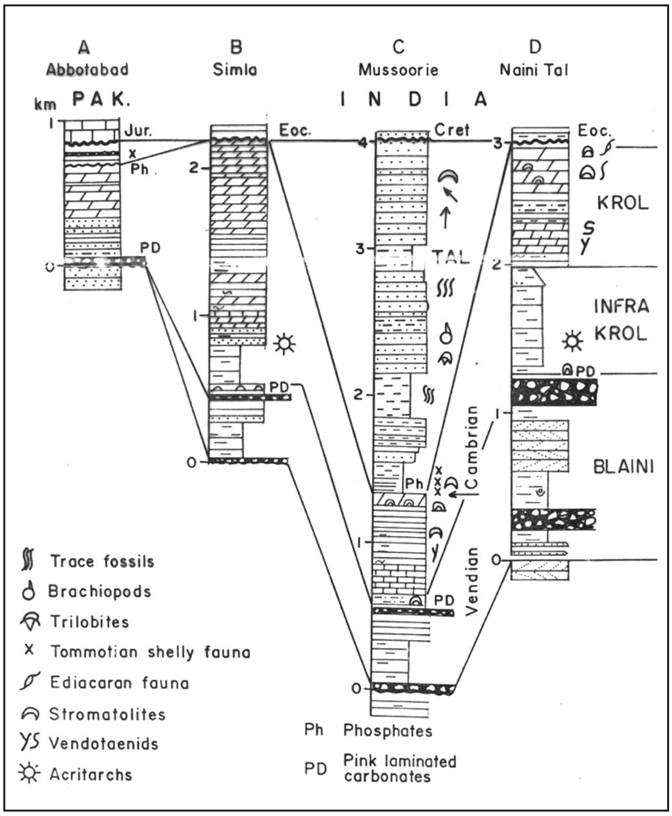

Fig. 4: Neoproterozoic- Lower Cambrian biostratigraphy of the Lesser Himalaya (Mussoorie Syncline) and correlation of Blaini-Krol-Tal succession with adjoining south Asian section.

Vendotaenids (metaphytes), trace fossils and Ediacaran fossils. It is also strongly supported by the carbon and oxygen isotope chemostratigraphy from Lesser Himalayan carbonates (Figs. 4, 5, 6, 7). There is striking similarity between Neoproterozoic –Early Paleozoic Tandilia System in the Rio de la Plata craton of eastern Argentina,Sierras Bayas Group, Cerro Negro and Balcarce Formations (Fig. 8; Poire´ and Gaucher, 2009; Cingolani, 2010).

Pre Ediacaran (Meso-Neoproterozoic) stromatolitic carbonate sedimentation in Eastern India (Sikkim – Arunachal Lesser Himalaya)

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 stromatolitic cherty carbonates and quartzites (Figs. 9, 10). Dolomitic carbonates are characterized by stromatolites of Meso and Neoproterozoic (Russian Riphean Period; Raaben and Tewari, 1987; Tewari, 1989, 1993, 2004, 2011). Microbiota in the cherty dolomite further confirms Meso-Neoproterozoic age for these rocks (Schopf et al., 2008; Shukla et al., 1987, 2006; Tewari, 1989, 2004, 2008, 2009, 2011, 2017a). 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, 2011). The Lower Gondwana sediments were deposited during the early Permian marine transgression in different parts of the NW and NE Lesser Himalaya (Valdiya, 1997). The signatures of Permo-Carboniferous global glaciations are preserved in the Tatapani area of the Rangit window in south Sikkim Lesser Himalaya (Figs. 9, 10). 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 (Fig. 10). 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.Carbon and oxygen isotope chemostratigraphy of the Buxa Dolomite shows shallow marine depositional environment (Fig. 11). 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., Vinodella, a new form are developed in the Eastern Himalaya (Tewari, 2011, 2017a; Kumar et al., 2020). The chert bands associated with the stromatolites in Arunachal and Sikkim Lesser Himalaya have yielded organic walled microfossils Siphonophycus sp., Eomycetopsis sp., Obruchevella sp., Myxococcoides sp. and Oscillatoriopsis sp. (Shukla et al., 2006; Schopf et al., 2008; Tewari, 2003, 2007, 2009a,b, 2011, 2017a). The Laser Raman Spectroscopy and Confocal Laser Scanning Microscopy have shown that these bacteria are biogenic (kerogen) and can be considered proxies for the extraterrestrial life on other planets (Tewari, 2011, 2017b). The highly diversified microorganisms recorded from the Buxa Dolomite have astrobiological significance and stromatolites, microbial mats and bacteria like features are likely to be found on the Martian surface (Schopf et al., 2008; Tewari, 2011, 2017a). 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 Sikkim- Bhutan Himalaya. On the other hand, the Permian glaciation is well represented in the South Sikkim Himalaya near Tatapani in the form of Rangeet Boulder Beds and Rangeet Pebble Slates of Gondwana time (Figs. 12, 13). These glacial diamictites indicate cooler Permian climate for the eastern Himalayan basins.

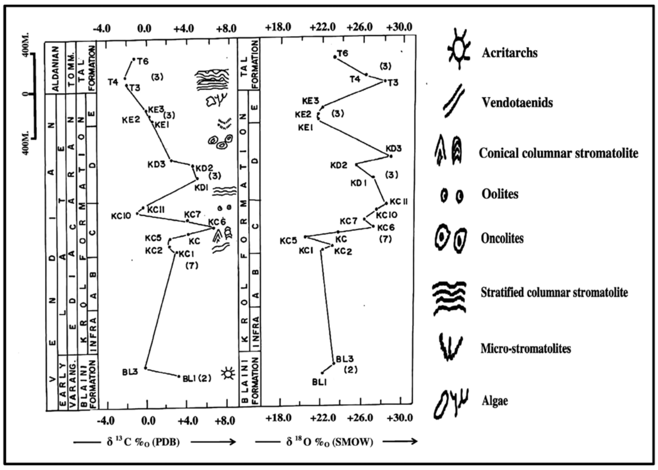

Fig. 5: Carbon and oxygen isotope chemostratigraphy of the Blaini-Krol-Tal (Cryogenian-Ediacaran-Lower Cambrian) succession of the Lesser Himalaya, India (Tewari and Sial, 2007).

CARBON AND OXYGEN ISOTOPE CHEMOSTRATIGRAPHY

Neoproterozoic –Cambrian Boundary Chemostratigraphy of Lesser Himalaya, India

$\delta^{13}C$ chemostratigraphic profiles for the Mussoorie and Garhwal

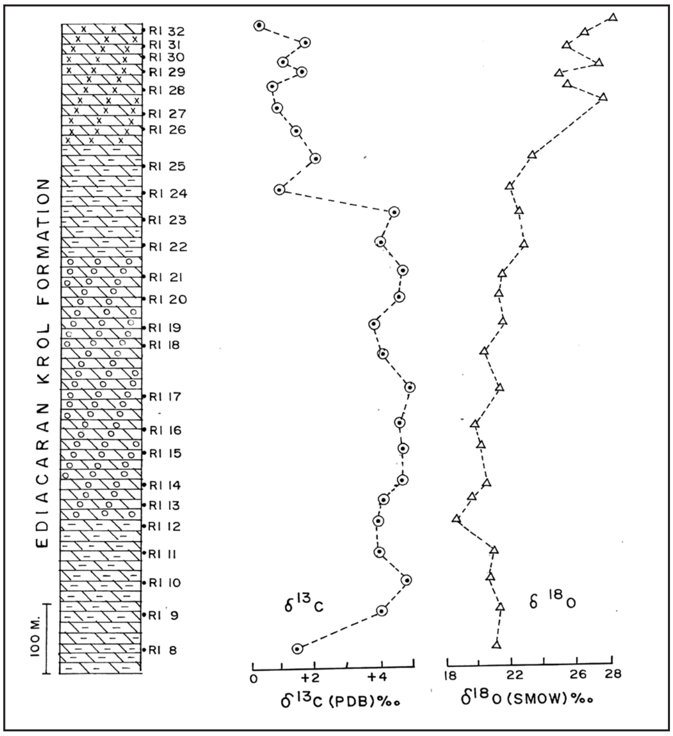

Fig. 6: Carbon and oxygen isotope chemostratigraphy of the Ediacaran Krol Formation, Rikhnikhal section, Garhwal Lesser Himalaya, India.

synclines of Tehri and Pauri Garhwal regions of the Uttarakhand Lesser Himalaya, India has been studied and compared (Figs. 5, 6, 7). A composite profile of δ^{13}C for the Krol Formation (Ediacaran System) from the Rikhnikhal (Fig. 6) and Kauriyala (Fig. 7) sections of the Garhwal syncline substantiates the isotopic profile obtained from the Mussoorie syncline (Tewari, 1991, 2007, 2012; Tewari and Kumar, 1995; Tewari and Sial, 2007). The Blaini diamictites are well developed in both sections representing the Neoproterozoic glacial Marinoan / Blainian event. The Blaini pink cap microbial carbonate shows a negative δ^{13}C excursion characteristic of cap carbonates globally. At the Luxmanjhula section, near Rishikesh, the δ^{13}C values for a stromatolitic pink cap limestone of the Cryogenian Blaini Formation varies from -1.73 to -1.86‰ PDB. Oxygen isotopes range from -9.13 to -11.63‰ PDB in carbonates. The Lower Krol Formation is composed of shaly limestone and marl. δ^{13}C values rise to +4.93‰ PDB in the overlying Krol C dolomite in Rikhnikhal area, which rise to +6‰ PDB in the Mussoorie syncline (Figs. 5, 6). The Upper Krol carbonates are cherty, oolitic and stromatolitic-oncolitic, and zebra fabric is well developed. Krol D/E Member has yielded well-preserved Ediacaran medusoids and frondose forms in the upper silty layers. A negative excursion has been recorded (δ^{13}C −10.52‰ PDB) just below the Ediacaran-Lower Cambrian boundary (Tewari, 2012). The Ediacaran C-isotope stratigraphy of the Krol Formation (Krolian) of the Lesser Himalaya is identical to the Doushantuo, Lower Dengying and Upper Dengying Formations of South China and also comparable with the global data (Tewari and Sial, 2007). The palaeogeographic reconstruction of the palaeo-continents suggests that around 650–540 Ma, Lesser Himalaya and South China were very close to each other. The published paleogeographic and palaeomagnetic data during this period show strong evidence for the existence and breakup of the Rodinia Supercontinent followed by the Pan African/Pan Indian orogenic event, which reassembled the Gondwana Supercontinent.

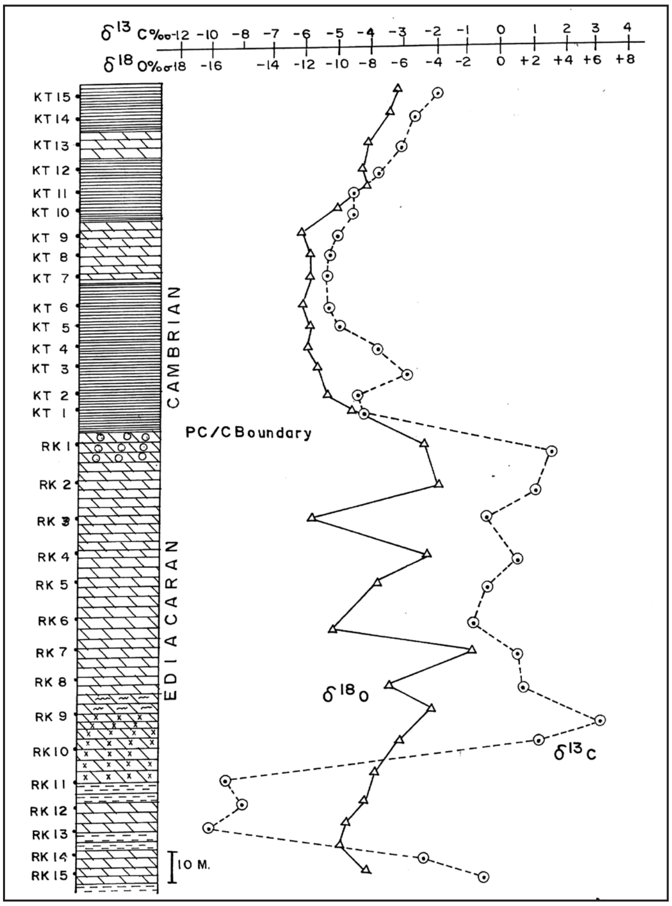

Fig. 7: Carbon and oxygen isotope chemostratigraohy of Krol-Tal formations at Kauriyalaghat section, Garhwal Himalaya.

Correlation of Ediacaran – Lower Cambrian sedimentation in Western and Eastern Gondwana

Neoproterozoic – Early Paleozoic successions in western Gondwana, South America are recorded in many sedimentary basins of Brazil, Paraguay, Uruguay and Argentina. (Fig. 8; Arrouy et al., 2016, 2019; Afonso, and Nogueira, 2018; Gaucher, 2018; Gaucher et al., 2004, 2008a,b; Gaucher and

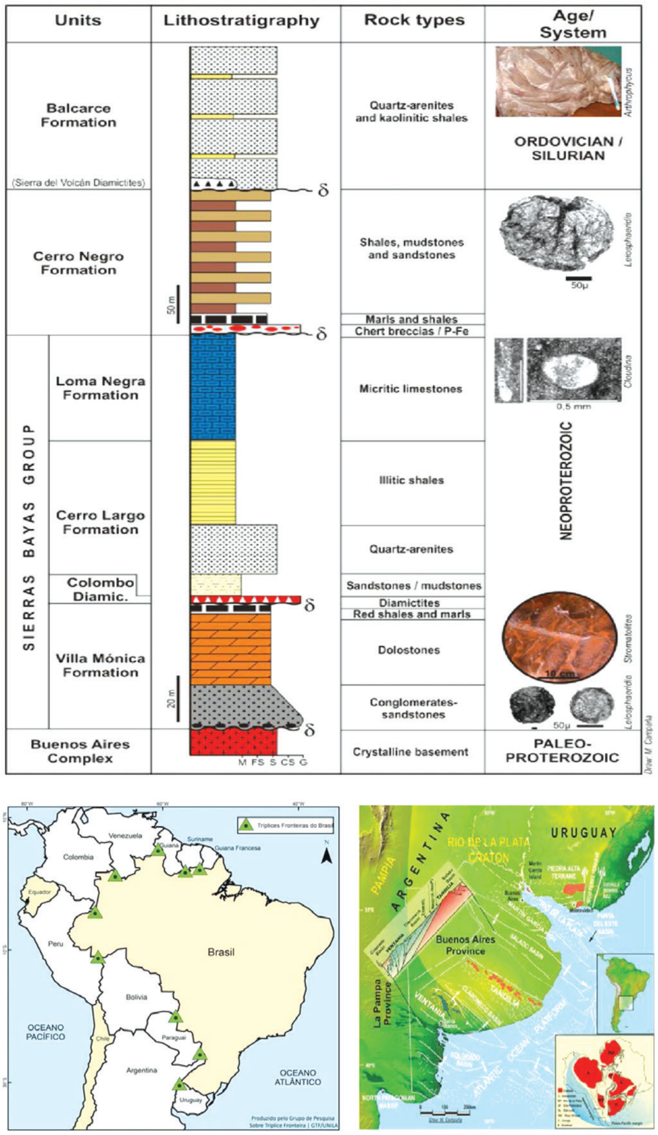

Fig. 8: Location map of South American countries having western Gondwana basins with political boundaries Tandilia System in the Rıo de la Plata craton of eastern Argentina and Integrated lithostratigraphic column of the Neoproterozoic-Early Paleozoic Sierras Bayas Group, Cerro Negro and Balcarce Formations (based on Poire´ and Gaucher, 2009; Cingolani, 2010).

Poire, 2009; Gomez-Peral et al., 2007, 2014, 2017; 2018; Misi et al., 2006; Poire, 1989; Poire et al., 2018; Poire and Gaucher, 2009, Sial et al., 2000, 2016; Warren et al., 2011, 2014, 2017; Zimmermann et al., 2011). The Cryogenian to Uppermost Ediacaran successions of the Tandilia System (Sierras Bayas Group and Cerro Negro Formation) in central-eastern Argentina is unmetamorphosed, undeformed and deposited in glacio-marine to shallow marine warm water tidal flat environment (Fig. 8).

In Eastern Gondwana, similar well-developed successions are recorded from Lesser Himalaya in north India and their equivalents in Peninsular Indian basins (Tewari and Sial, 2007; Tewari, 2012, 2022; Tewari and Seckbach, 2011). The Neoproterozoic glacial diamictites/tillites and cap carbonates indicative of Snow Ball Earth (Marinoan/Blainian glaciation) is an important Cryogenian stratigraphic marker bed well developed in western and eastern Gondwana basins and paleoclimatically and isotopically correlated (present study). The thick Ediacaran age carbonate- siltstone-shale facies successions are overlying these glacial beds and have yielded well preserved Ediacaran fossils, stromatolites, microorganisms in cherts, acritarchs, vendotaenids, trace fossils, microbially induced sedimentary structures in southwest and eastern Gondwana basins (Arrouy et al., 2016, 2019; Afonso, and Nogueira, 2018; Poire´ and Gaucher, 2009; Gaucher, 2004, 2018; Warren et al., 2011, 2014, 2017; Tewari, 1984, 1989, 1992, 2007, 2011, 2012). These Cryogenian-Ediacaran (Blaini – Krol sediments in Lesser Himalaya, India) are glaciomarine, warm marine oolitic carbonate –siltstone-shaly tidal flat deposits, and have shown identical carbon and strontium isotopic ratios (Tewari and Sial, 2007; Tewari and Tucker, 2011; Tewari, 2012). The Neoproterozoic – Lower Cambrian transition is marked by Tal Formation in the Lesser Himalayan basins of India in Eastern Gondwana, characterised by the small shelly fossils and stromatolites in phosphorite and trace fossils, trilobites and brachiopods in the siltstone facies (Figs. 3, 4, 5). However, the phosphogenic events are recorded from the Ediacaran sediments in western Gondwana (Gomez Peral et al., 2014). The Precambrian – Cambrian boundary transition needs to be studied in detail in the South American basins of Southwestern Gondwana for global correlation. The Earth's history, stratigraphy and paleoclimate during the Neoproterozoic and Lower Paleozoic Period recorded from the Western Gondwana in South America (Amazonia Craton, North Paraguay Belt, Southern Paraguay Belt, Brazil, Río de La Plata Craton (Tandilia System, Buenos Aires, Argentina, Cingolani, 2010, Fig. 8) and Pan Indian Eastern Gondwana basins of Lesser Himalaya and the equivalents from Indian subcontinent will help in reconstruction of paleogeography and paleomagnetism of the Supercontinent Gondwanaland and its correlation with Africa, Australia and Antarctica in Eastern Gondwana.

BREAKUP OF RODINIA SUPERCONTINENT: PALEOZOIC PALEOGEOGRAPHY AND PALEOCLIMATE

The major Paleozoic continents are recognized after Rodinia breakup. Laurentia included North America, Greenland and Scotland while northern Europe and Russia was part of Baltica. All these continents were located at low paleolatitudes. There

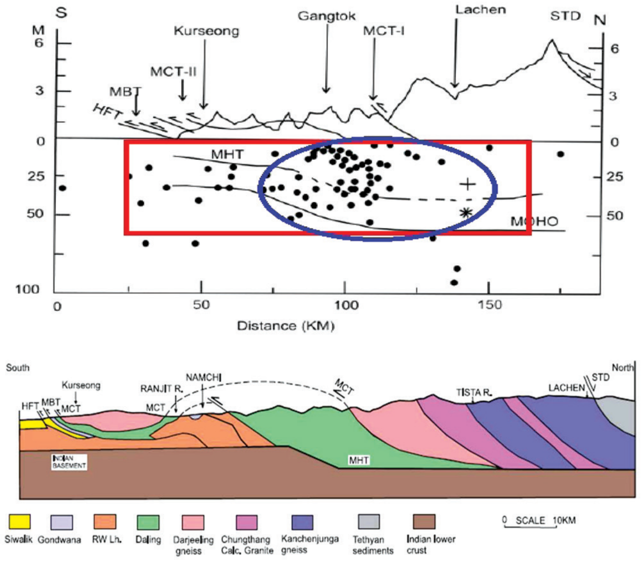

Fig. 9: Geological cross section, major lithotectonic and seismic profile of the eastern Himalaya (Darjeeling-Sikkim sector compiled from various sources). The Lesser Himalayan Proterozoic Buxa Formation and Permo-carboniferous Gondwana basins are located in Ranjit River section and Namchi town, south Sikkim (Tewari, 2011; GSI, 2012) between Main Boundary Thrust (MBT) and Main Central Thrust (MCT). Tethyan peri-Gondwana basin lies in north Sikkim separated by South Tibetan Detachment (STD; Tewari et al., 2022). The Sikkim- Darjeeling Himalaya is seismically active zone of India.

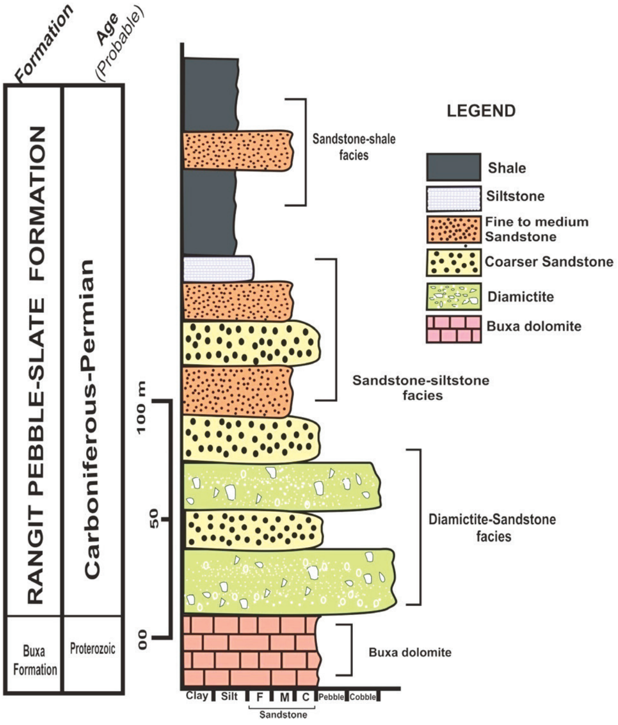

Fig. 10: Lithostratigraphy of the Buxa Formation (Meso-Neoproterozoic) and Carboniferous – Permian Gondwana glacial Rangeet diamictite- sandstone, Sandstone- Siltstone and Sandstone – Shale sedimentary facies exposed in Rangit Window, south Sikkim.

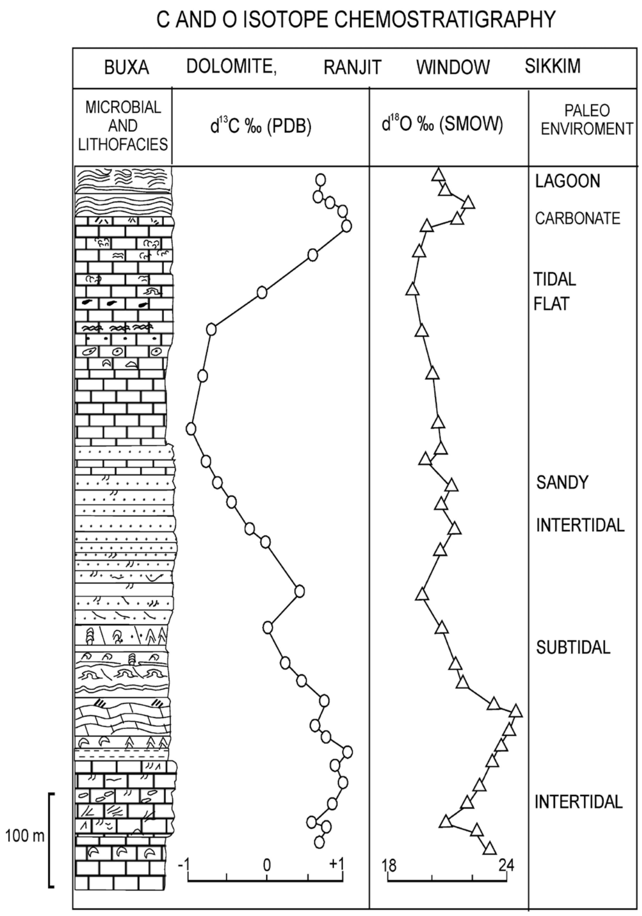

Fig. 11: Carbon and oxygen isotope chemostratigraphy and depositional environment of the Meso-Neoproterozoic Buxa Dolomite Formation, Rangit River valley, Sikkim Himalaya. The isotopic ratios and stromatolitic sedimentary macro and microfacies are different than Ediacaran sediments of the Krol Formation in western Himalaya not developed in eastern Himalaya.

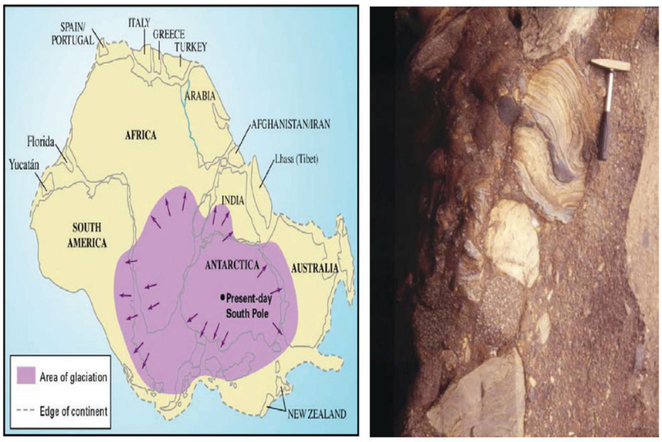

Fig. 12: Global Pennsylvenian Lower Gondwana cryosphere showing paleoflow direction of glaciers (left, compiled from various sources) and field evidence from South Sikkim, Eastern Lesser Himalaya, India (Rangit Boulder beds, diamictites and big stromatolitic clasts derived from the Daling Quartzite- Phyllites and Buxa Dolomite indicating proximal provenance, right).

were no major glaciers at polar regions and oceanic water circulation was free. Paleozoic period was mostly warm, but two glacial times, Ordovician and Pennsylvanian to Late Permian (Gondwana glaciation) has been recognized. Gondwanaland included the assembly of southern continents and India. Paleogeographically Carboniferous – Permian diamictite, coal beds and plant fossil bearing Gondwana outcrops are found in South Sikkim and Arunachal Lesser Himalaya of Northeast India. In North Sikkm Tethyan basin (Lachi Formation), the Gondwana sediments are correlated with Rangit window and occupies the peripheral position in Himalayan Gondwana (Raina and Bhattacharyya, 1975). The sedimentary facies, petrography of glacial diamictites and geochemical studies have strongly supported this correlation. The Permian period witnessed rifting and consequent formation of the Gondwana basin, volcanism and marine transgression in the Peninsular and the Lesser Himalaya and represent a major hiatus in the Tethyan Himalaya (Bhargava, 2011; Tewari et al., 2002 and references thein).

Extensive Gondwana tillites/diamictites and striations were formed due to sea level fluctuations, glacial regression and interglacial cyclic deposition during Pennsylvanian (Permian times; Figs. 10, 12, 13). Large continents of Gondwanaland Supercontinent South America, Africa, India, Australia and Antarctica were located over the South Polar region and global equatorial to polar oceanic circulation was blocked and may have been the main cause of glaciation (Tewari et al., 2022). Coal deposits were generated after the deglaciation in Gondwanaland. Indian master basin Gondwana coal in Damuda Formation was formed during this period (Casshyap and Srivastava, 1988). The equivalent of coal bearing Damuda Sandstone is well develop in and around Namchi town and Rangit Window named as Namchi Sandstone in South Sikkim Lesser Himalaya (Figs. 9, 13). Paleogeographically, these Carboniferous – Permian diamictite, coal beds and plant fossil Glossopteris sp. bearing Gondwana outcrops are found in South Sikkim and Arunachal Lesser Himalaya of Northeast India (Fig. 13). In North Sikkm Tethyan basin (Lachi Formation), the Gondwana sediments are correlated with Rangit window and occupies the peripheral position in Himalayan Gondwana

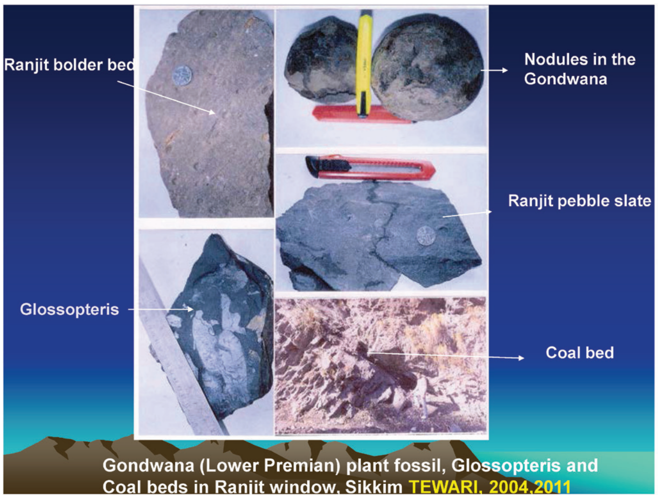

Fig. 13: Lower Gondwana glacial boulder beds, pebble slates, carbonaceous nodules, coal beds and plant fossil Glossopteris well preserved in the Rangit window, south Sikkim, Lesser Himalaya.

(Tewari et al., 2022 and references therein). The sedimentary facies, petrography of glacial diamictites and geochemical studies have strongly supported this correlation (Tewari et al., 2022). Major tectonic units (Himalayan Frontal Thrust, Main Boundary Trust, Main Central Thrust and South Tibetan Detachment), seismicity and geological profile from Sub-Himalayan Siwalik, Lesser Himalaya, Central Crystallines and Tethyan sediments is shown in Figure 9. The major structural zones of the Himalaya including the Tethyan Himalaya (TH), Greater Himalaya (GH), Lesser Himalaya (LH), and Sub-Himalaya (Siwaliks) are continuous along the entire length of the mountain belt from Jammu in NW to Darjeeling in NE (Thakur, 1987; Valdiya, 2002).

GONDWANA (PERMIAN –TRIASSIC) BOUNDARY IN TETHYS HIMALAYA, INDIA

Permo-Triassic boundary marks the mother of all extinction event in earth's history when more than 90% marine species were wiped out and a totally new scenario of marine fauna emerged in Mesozoic. The Permian –Triassic boundary also marked a global regressive event that affected the sequence in Tethys Himalaya (Shah, 2022). Triassic rocks in Tethys Himalaya cover almost the entire System and there are no breaks in sedimentation. The best sequence of Triassic is developed in Guryul Ravine near Srinagar, Kashmir. The Triassic marine sediments are completely absent in the Lesser Himalaya and Peninsular India. Ghosh et al., 2016, 2002) reported detailed stable carbon isotope data on samples from the Spiti Valley sections. Record of seismite and tsunamite deposits in Guryul ravine in Kashmir during the Late Permian Event Horizonis an important event (Brookfield et al., 2013). The Spiti sections demonstrates a sudden change from deep-water to a shallow oxidizing depositional environment for the Neo-Tethyan sediments, associated with an abrupt phase of marine regression. Ghosh et al. (2016) have interpreted that Late Permian sediments were derived from the Panjal volcanics and deposited under oxic to suboxic conditions in a shallow shelf region. Late Permian organic carbon isotope pattern in Spiti sections are considered relatively stable (-24‰ to -26‰) when compared to the type area in Meishan section, China which shows depleted carbon isotope values (-27‰ to -31‰). Tewari et al. (2022) have also recorded negative organic carbon isotope data from Tethyan section of North Sikkim Himalaya. $\delta\ ^{13}C$% (VPDB) from Gondwana shales range between -24.6‰ and -26.5‰. Total organic carbon (TOC) varies in these samples from 0.13 to 0.19. It is consistent with other known isotopic data from other regions of the world.

CRETACEOUS – TERTIARY BOUNDARY CHEMOSTRATIGRAPHY IN MEGHALAYA, NORTH EAST INDIA

The Um Sohryngkew section of Meghalaya, NE India, located 800-1000 km from the Deccan volcanic province is one of the most complete Cretaceous-Paleogene boundary (KTB) transitions worldwide with strong evidence of mass extinction of planktoic foraminifera, larger ammonoids and other fossils, first appearance of Danian foraminiferal species, negative shift in the $\delta^{13}C$, KTB red clay layer wth Ir anomaly of 12 ppb (Sial et al., 2016, 2019; Tewari and Sial, 2015; Tewari, 2019 and references therein). Geological map of the Cretaceous-Tertiary and Paleocene – Eocene sections around Um Sohryngkew river, Shillong Plateau, Meghalaya, NE India is shown in Figure 14 (Tewari et al., 2010a,b). Distribution of Paleocene – Eocene larger benthic foraminifera and calcareous algae in Eastern Tethys sea and their depositional environment in Shillong Plateu, Meghalaya is reconstructed (Fig. 15).

We have analysed this section for C, O and Hg isotope chemostratigraphy as shown in figure 14. The carbon and oxygen isotope variation in the Cretaceous – Tertiary boundary has been studied (Fig. 16). $\delta^{13}C$ varies from – 0.01 ‰ (VPDB) below the K/ T boundary to -9.79‰ (VPDB) at the K/T boundary (KT8a). The value of oxygen isotope ratio ($\delta^{18}O$) is -4.89%0 (VPDB) at the K/T Boundary. The value of $\delta^{13}C$ just above the K/T boundary (KT 9) is + 0.51‰ (VPDB) and the $\delta^{18}O$ is –11.04‰ (VPDB). The total range of $\delta^{13}C$ below the K/T boundary is between – 0.01‰ (VPDB) to + 0.95‰ (VPDB) and the range of $\delta^{18}O$ is from – 10.31‰ (VPDB) to -12.65‰ (VPDB).The total variation in $\delta^{13}C$ above the K/T Boundary is from -0.01‰ (VPDB) to +1.35‰ (VPDB) and $\delta^{18}O$ is in the range of -7.81‰ (VPDB) to -13.03‰ (VPDB). Mercury isotope chemostratigraphy at Um Sohryngkew section yielded $\delta^{202}Hg$ values of −1.61‰ (spike I) and −1.89‰ (spike II) and $\delta^{201}Hg$ close to 0.0‰. (Sial et al., 2016). The

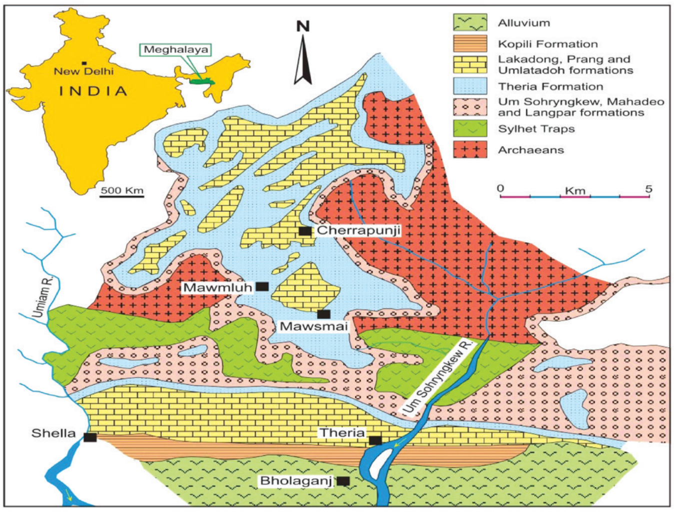

Fig. 14: Geological map of the Cretaceous-Tertiary and Paleocene – Eocene sections around Um Sohryngkew River, Shillong Plateau, Meghalaya, NE India (Tewari et al., 2010a,b).

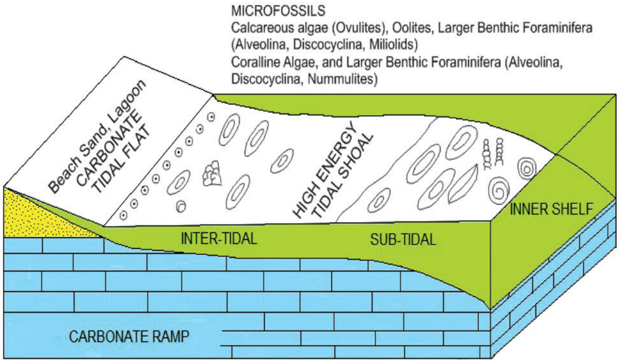

Fig. 15: Distribution of larger benthic foraminifera and calcareous algae in eastern Tethys sea, Shillong Plateu, Meghalaya and their depositional environment in Paleocene-Eocene age limestone.

three Hg/TOC spikes present in the Højerup, Bottaccione, and Um Sohryngkew sections are probably associated with the Deccan phase 2 eruptions, as well as the two spikes at the Poty section. One of these spikes (spike I) is situated within the CF2 foraminiferal biozone (e.g., Um Sohryngkew), within the 250 ky (beginning of Deccan phase 2) to 160 ky (CF2–CF1 biozones boundary) interval before the K-Pg boundary and after carbon dioxide, sulfuric aerosols, and other toxic agents had reached a critical threshold. The second spike (spike II), at the K-Pg boundary, is also concomitant with the Deccan phase 2 (e.g., Højerup and Bottaccione), and a third one (spike III), within the P1a foraminiferal zone. Similar isotopic ratios have been recorded for the Jhilmili section of Central India (Fig. 16). In conclusion, a global paleogeographic map for the Cretaceous – Tertiary boundary based on the distribution of the mercury, carbon and oxygen isotopes in different sections of the northern and southern hemisphere has been established which suggest that the major issue of the mass extinction is due to Deccan volcanism at Cretaceous – Tertiary boundary (Sial et al., 2016, 2019; Tewari, 2019 and references therein).

INDIA–ASIA COLLISION AND POST COLLISION LARGER BENTHIC FORAMINIFERA FROM EASTERN AND WESTERN TETHYS: PALEOBIOGEOGRPHIC IMPLICATIONS

India–Asia plate collision and uplift of the Himalaya took place during Paleocene-Eocene time (50 Ma). The extension of western Tethys Sea from Europe to Asian eastern Tethyan region has been correlated by assemblages of Larger Benthic Foraminifera (LBF). Global correlation and paleobiogeography of the eastern Meghalayan and western Tethyan basin is based on SBZ of Paleocene- Eocene foraminifera assemblages (Hottinger, 1971). The similarities between NE India, NW Himalaya, Ladakh, Karakoram, and Southern Tibet suggest that all these regions belonged to a single faunal province during the Paleocene - Eocene period (Tewari, 2019 and references therein). Tethyan Himalaya persisted at the northernmost Indian Plate, representing a passive continental margin until the end of the Paleocene. Paleozoic to Cretaceous marine sedimentary strata are widely exposed within the Tethyan Himalaya, whereas the Paleocene - Lower Eocene shallow-water limestones developed mainly in the southern Tethyan Himalaya. The Sylhet Limestone Group in Meghalaya (North-East India) comprises a thick succession of Paleogene carbonates and clastics,ranging from Late Paleocene to Early Eocene. Rich assemblages of larger benthic foraminifera and coralline algae occur extensively in these shallow water carbonate ramp deposits (Kalita and Gogoi, 2003; Borgohain, 2018; Sarkar, 2016, 2017; Tewari et al., 2010a,b; Tewari, 2019) (Fig. 17). The present study deals with the paleobiology and paleobiogeography of the Lakadong Limestone (lower unit) and the Umlatodoh Limestone (middle unit) of the Sylhet Limestone Group. These two limestone units represent a major Tethyan marine transgression during the Palaeocene in the South Shillong Plateau. The larger benthic foraminifera are commonly represented by the assemblage Alveolina sp., Assilina sp., Nummulites sp., Discocyclina sp. and also Miliolids, Ranikothalia and Rotaliids.The algal assemblages include *Sporolithon* sp., Lithophyllum sp., Jania sp., Corallina sp., and *Distichoplax biserialis* (Lokho and Tewari, 2011, 2012). The Sylhet Limestone Group was deposited in a prolonged marine transgressive phase. A large transgression occurred during the Upper Paleocene when an arm of sea from the Eastern Tethys covered extensively the Shillong Plateau. Subsequently, two major marine transgressions covered the Shillong Plateau during the Early Eocene which is represented

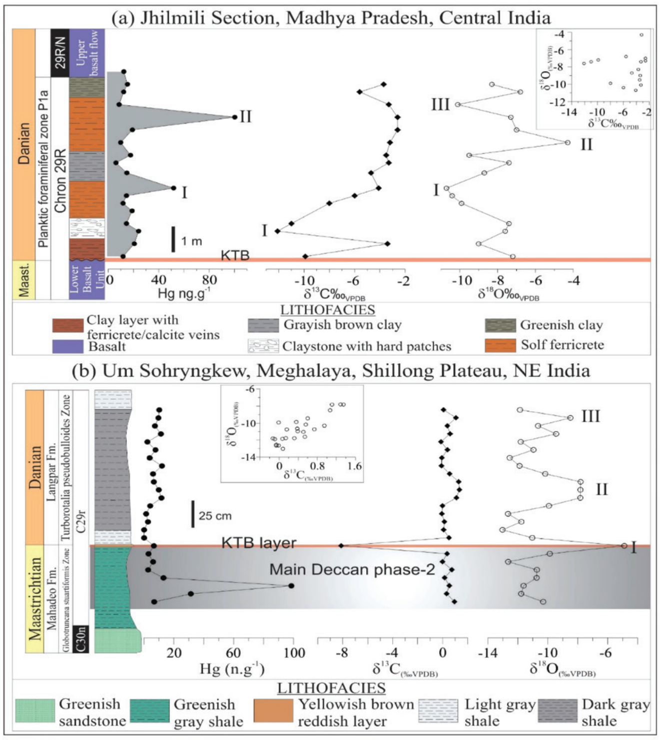

Fig. 16: Cretaceous –Tertiary boundary C, O and Hg isotope chemostratigraphy established at Um Sohryngkew section in Meghalaya, NE India and Jhilmili section , M.P., Central India (Sial et al., 2016, 2019).

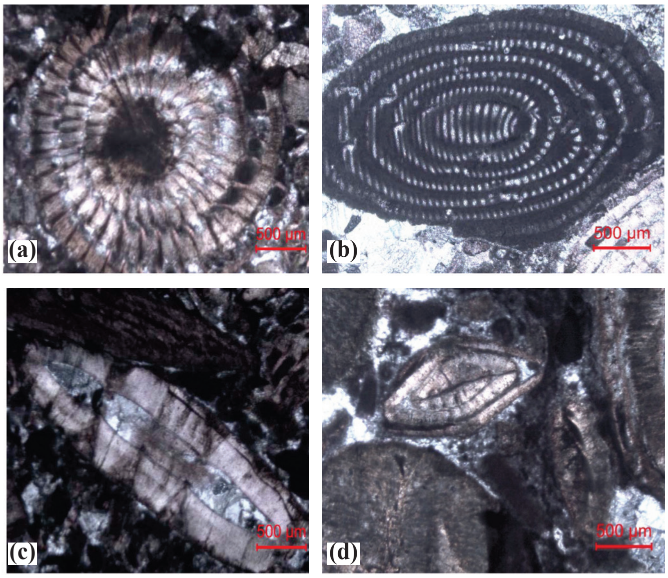

Fig. 17: Larger benthic foraminifera assemblage from Lakadong Limestones, Meghalaya (a) Nummulites sp., (b) Alveolina sp., (c) Nummulites sp. (axial section), (d) Discocyclina sp.

by the Umlatodoh Limestone. The Middle Eocene to Early Upper Eocene is represented by the Prang Limestone. Larger foraminifera and calcareous algae has also been recorded from the Indo-Myanmar Orogenic Belt (IMOB) in Manipur and compared for the paleobiogeography of Meghalaya with that of the IMOB.The IMOB represents the eastern suture of Indian Plate and it was formed due to the collision of the Indian plate with the Myanmar Plate (Singh et al., 2015, 2022 and references therein; Tewar et al., 2011; Tewari, 2019). The Naga-Manipur ophiolites has been assigned to range in age from Upper Cretaceous to Eocene on the basis of faunal assemblages (radiolaria, planktonic foraminifera) in the olistolithic blocks of pelagic limestone and cherts (Singh et al., 2015; Tewari et al., 2011). The Lower Disang sediments were intermixed with pelagic cherts and limestone. The flyschoid Disang Formation gradually merges into the post-orogenic molassic Barail Group of rocks.

PALEOCENE – EOCENE CHEMOSTRATIGRAPHY OF SHILLONG PLATEAU, MEGHALYA, INDIA

The Umlatodoh Limestone is characterised by the larger benthic foraminiferal taxa of early Ilerdian and Middle Eocene (early Lutetian age) has been analysed for the first time for isotopic ration variation in carbon and oxygen isotopes. Carbon and Oxygen isotope chemostratigraphy of Paleocene- Eocene Umlatodoh Limestone, Meghalaya across shallow benthic zones SBZ7 and SBZ8 of western Tethys shallow benthic assemblage zones is shown in Figure 18. The Umlatodoh Formation has yielded mainly larger foraminifera and calcareous algae. Important species include Alveolina sp., Assilina sp., Discocyclina sp., Nummulites sp. (Fig. 18). Calcareous algae Halimeda sp., Sporolithon sp. Ovulites sp. and Spongites sp., along with some bioclasts are also recorded (Borgohein et al., 2018; Tewari, 2019). The lower part of Umlatodoh Limestone δ^{13}C ratio varies from -0.082‰ (PDB) to 1.34‰ (PDB) and δ^{18}O ratios varies from -6.84‰ (PDB) to -8.22‰ (PDB). The middle part shows variation in δ^{13}C isotope ratio from 0.44‰ (PDB) to 1.56‰ (PDB) and δ^{18}O isotope isotope ratio varies from -7.60‰ (PDB) to -12.24‰ (PDB). Upper part of the Umlatodoh Limestone shows δ^{13}C isotope ratio variation from -0.12‰ (PDB) to 1.84‰ (PDB) and δ^{18}O isotope ratio is in the range between -6.48‰ (PDB) to -8.60‰. The present carbon and oxygen isotope chemostratigraphyis comparable with the shallow marine values of the limestone and indicate shallow tidal depositional environment for the Umlatodoh Limestone.

CARBON AND OXYGEN ISOTOPE CHEMOSTRATIGRAPHY OF MANIPUR OPHIOLITE MELANGE CARBONATES, NE INDIA

The exotic limestone of the Manipur- Ophiolite melange zone has yielded rich assemblages of planktonic foraminifera with a lesser abundance of benthic foraminifers. The planktonic foraminiferal taxa include *Globotruncana arca, G. lenneiana, G. dupeublei, G. orientalis, G.sp., Globotruncanita conica,* Pseudotextularia sp., *Heterohelix striata, H. globulosa, H. punctulata, Heterohelix sp., Contusotruncana contusa, C. patelliformis, Pseudoguembelina costulata.* The benthic foraminifers are represented by Ammonoides cibicides, Dentalina communis, Fissurina sp., and Globorotalites sp. Among the planktonic foraminifers such as Globotruncana sp., Heterohelix sp., and Pseudotextularia sp. may indicate open sea condition or a trend toward open sea condition (Tewari et al., 2011; Singh et al., 2015; Singh et al., 2022 and references therein). The Manipur ophiolite zone carbonates are depleted in δ^{13}C per mil (PDB) varies from + 1.02 to + 1.570 and δ^{18}O (PDB) range from -6.37 to -9.00%) values suggesting marine precipitates (Tewari, 2011; Singh et al., 2022) (Fig. 19). Further, their Euanomalies and spread in negative δ^{18}O (PDB) values to a lesser extent of δ^{13}C (PDB) values also suggest their formation was altered by diagenesis in the shallow marineenvironment (Tewari et al., 2011; Singh et al., 2015; Singh et al., 2022).

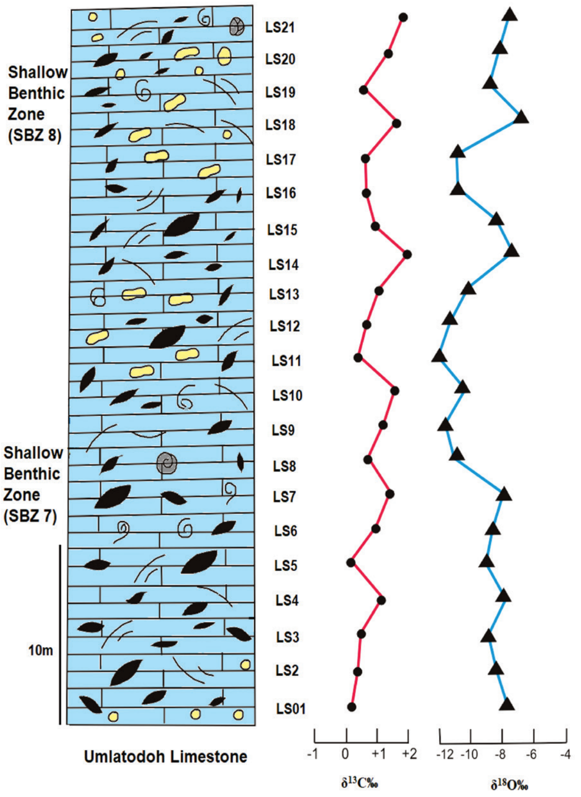

Fig. 18: Carbon and oxygen isotope chemostratigraphy of Paleocene- Eocene Umlatodoh Limestone, Meghalaya across shallow benthic zones SBZ7 and SBZ8 of western Tethys shallow benthic assemblage zones.

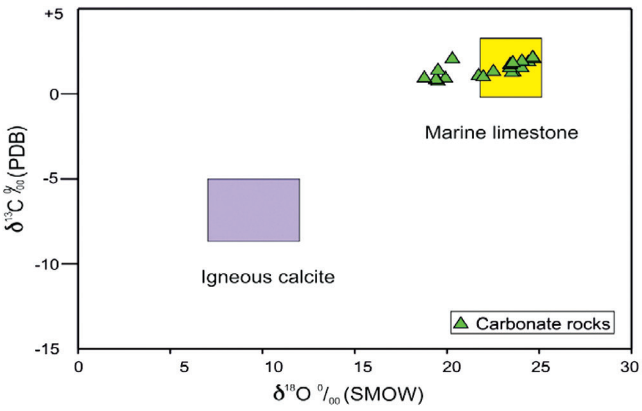

Fig. 19: δ^{18}O (SMOW) and δ^{13}C (PDB) plots for carbonate rocks of the ophiolitic melange zone, Indo –Myanmar orogenic Belt, NE India (Tewari et al., 2011; Singh et al., 2022).

δ^{18}O (SMOW) and δ^{13}C (PDB) plots for carbonate rocks of the ophiolitic melange zone, Indo –Myanmarorogenic Belt, NE India is shown in Figure 19.

COLLISION OF INDIAN PLATE WITH EURASIAN AND MYANMAR PLATE

The Late Paleocene – Middle EoceneTethyan foraminiferal – algal carbonate biofacies are well developed after Late Cretaceous – Paleogene mass extinction event in the eastern Tethys, Meghalaya, east India. Tethyan Foraminiferal - algal biotic diversity is recorded from the Lakadong and Umlatodoh Limestones of the Sylhet Group well exposed in East Khasi and Jaintia hills, Shillong Plateau Meghalaya (Borgohain et al., 2018; Tewari, 2019; Figs. 16, 17, 18). These Tethyan benthic orthophragmine foraminiferal - algal limestones were deposited in the passive continental margin of a shallow marine carbonate shelf in eastern Tethys and Standard Benthic Zones (SBZ) of the Alpine- Adriatic western Tethys are recorded from Meghalaya. These sedimentary basins were developed after the separation and anti-clock wise northward movement of India from Australia and Antarctica in Late Cretaceous times (Fig. 20). The Cretaceous - Tertiary boundary is well marked in these basins by biotic mass extinction. Late Cretaceous mega ammonoid fossils and Sauropod dinosaur bones are abundantly found in the Maastrichtian Mahadeo Formation (Tewari et al., 2010a,b) The Indo-Myanmar Orogenic Belt (IMOB) represents the eastern suture of Indian plate and it was formed due to the collision of the Indian plate with the Myanmar plate. (Tewari et al., 2011; Singh et al., 2015, 2022). The Naga-Manipur ophiolites has been assigned to range in age from Upper Cretaceous to Eocene on the basis of faunal assemblages in the carbonate rocks. The carbon, oxygen and Hg isotope chemostratigraphy of the Pan Indian Pre and Post India – Asia Collision has been used to interpret the Paleogeography and Plaeoclimate of the Indian Subcontinent (Tewari, 2019) India continued its northward movement at a reduced speed after its first collision with Asian Plate in the NW Himalaya 60-65 Ma ago (Smith et al., 1994). One of the factors responsible for the reduction in speed could be the bouyancy effect caused by the subducting lighter Indian continent under the denser rocks of the Indus suture zone (Sharma, 1993). The continued northward push of the Indian plate after the collision, resulted stacking of various thrust slices of the metasedimentary cover rocks in the Lesser Himalaya (Figs. 2, 9). In northeastern Himalaya, the ophiolite rocks of the W-E trending Indus–Tsangpo Suture Zone (ITSZ) represents the remnants of the Neo- Tethys Ocean which were obducted on the surface during collision of the Indian and Eurasian Plates (Fig. 21). The ITSZ turned south - eastward at the eastern Himalayan syntaxis is offset northward by the Sagaing Fault and continues southward along the IMOB (Gansser, 1980). The ophiolite sequences occurring in the Tuting - Tidding Suture Zone in Arunachal Himalaya and IMOB have been considered as the south - eastern and southern extension of the ITSZ (Singh et al., 2021, 2022, 2015; Tewari et al., 2011; Tewari, 2019).

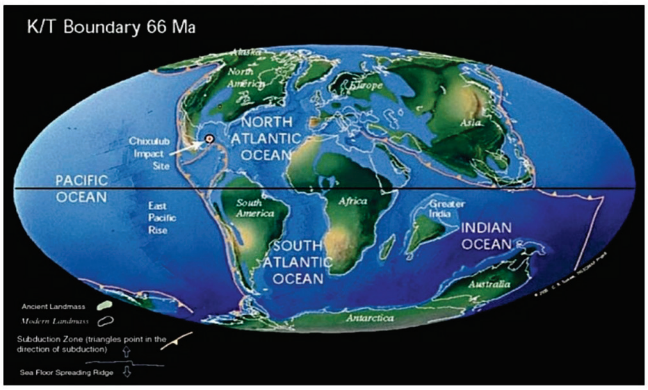

Fig. 20: Global Palaeogeography of the Cretaceous-Tertiary boundary (https://www.scotese.com) showing anticlockwise northward movement of Greater India (Indian Plate) around 66 million years ago before collision with Eurasian Plate in the north.

DISCUSSION AND CONCLUSION

The Ediacaran-Early Cambrian period must have been a time of continental extension and rifting in the Lesser Himalaya. The Krol carbonates are deposited in the peritidal carbonate ramp - shelf depositional environment (Tewari, 2002a.b, 2008, 2009; Jiang et al., 2003). Continental extension caused breakup of the Rodinia supercontinent and the creation of shallow epicontinental seas at low paleolatitudes in which Blaini- Krol-Tal Cryogenian diamictites, Ediacaran carbonates

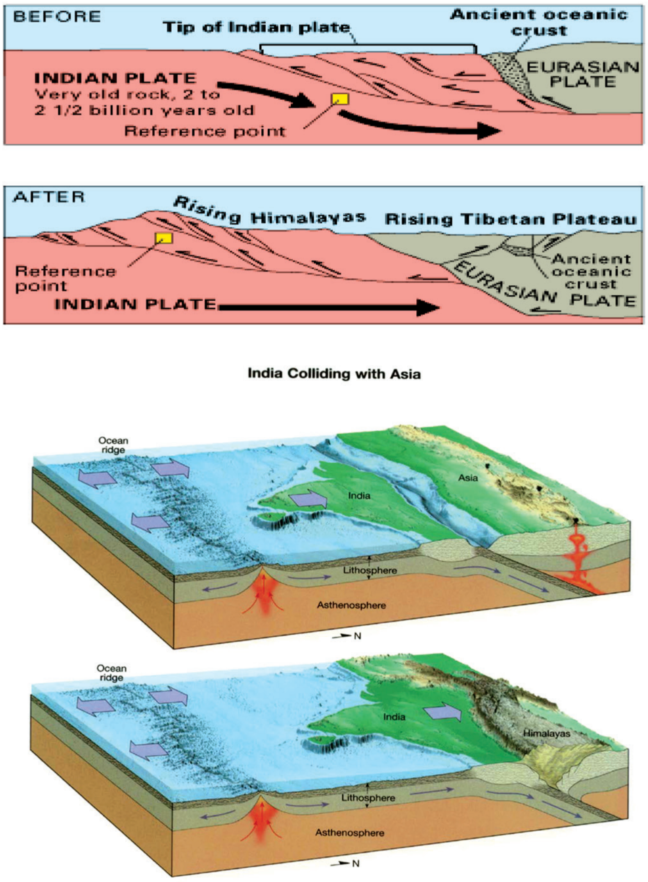

Fig. 21: The Himalayas were thrust up when India collided with Asia 50 million years ago. Paleoposition of Indian and Eurasian Plates before collision, northward movement of India and existence of intra plate Tethys sea (above) and after collision, subduction, disappearance of Tethys sea and emergence of Himalaya as a consequence of continent-continent collision around 50 Ma (Tewari, 2019).

and Tal phosphorite were deposited (Figs. 2, 3). The Lesser Himalayan sedimentation might have terminated due to Pan African orogeny around 500 Ma. which is strongly supported by the occurrence of granites of this age in Pan Indian subcontinent (Tewari, 2010). Paleoclimatic, C, O and S-isotopic, geochemical and palaeobiological events recorded in the Ediacaran (Neoproterozoic) - Early Cambrian age suggest that the continental assembly at this time of the Earth history remained at low latitudes (Tewari and Sial, 2007). Close association of evaporites, phosphorites and newly emerging metazoan fossil assemblages suggest favourable conditions for their evolution after the Snow Ball Earth event (Marinoan/Blainian glaciations). The Blaini Formation represents Neoproterozoic (Blainian) glaciation. Since its equivalent is not identified in the southern peninsula, it is unlikely to represent continental glaciations. It is interpreted that these rocks as products of valley glaciers, which merged with the sea. (Kumar et al., 2020). 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 (Tewari, 1992, 2007, 2010) and the Lower Cambrian stromatolitic - shelly fauna yielding phosphatic Tal Group, suggesting that the Krol-Tal contact is at the PC-C boundary. The Krol Group consisting of stromatolitic carbonates, indicates a warm climate (Tewari and Qureshy, 1985; Tewari, 2010a,b).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. The Krol Group, sandwiched between the 635 Ma Blaini and the upper most Ediacaran Earthy Siltstone Member should represent a 635-542 Ma interval (Fig. 3). 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 also prevailed during the Tal Group (Kumar et al., 2020).

Lower Cambrian Tal phosphate deposits of the Lesser Himalaya are stromatolitic, cherty, pyritic and shelly fossils are commonly found (Tewari, 1984, 1989, 1993). These were formed in lagoonal, peritidal environment and occasionally associated with evaporites. Phosphorites in the Lesser Himalaya (Krol-Tal basin), western Rajasthan (Birmania basin), Elburz Range (Haqf Group of Iran, Yunan and Sichuan provinces of South China, parts of Siberia, Mongolia, and Kazakistan are deposits have links with the evaporite accumulations.Lower Cambrian Phosphogenic event was a global event and used for palobiogeographic reconstructions and intercontinental correlation at the Precambrian - Cambrian boundary (Tewari, 2007, 2012). The Earth's history, stratigraphy and paleoclimate during the Neoproterozoic and Lower Palaeozoic Period recorded from the Western Gondwana in South America (Amazonia Craton, North Paraguay Belt, Southern Paraguay Belt, Brazil, Río de La Plata Craton Tandilia System, Buenos Aires, Argentina, Cingolani, 2010, Fig. 8) is correlated with Blaini-Krol-Tal Ediacaran – Lower Cambrian succession of the western Lesser Himalaya, India. The recent finds of Ediacaran acritarchs and microbially induced sedimentary structures from Tandilia System, Argentina by Arrouy et al. (2019) further substantiates this.

The Deoban dolomite around Chakrata in NW Himalaya (Figs. 1, 2, 3) and Buxa dolomite in Rangit Tectonic Window, Sikkim Himalaya (Figs. 9, 10, 11) display diverse organic walled microscopic fossils. There is a close similarity in the microfossil assemblages from the two regions. Several morphotypes exhibiting varying stages of cellular degradation and complex hydrocarbons (kerogen) and amino acids have been recorded using the Laser Raman Spectroscopy and CLSM techniques for the first time (Schopf et al., 2008; Tewari, 1989, 2001, 2011). Similarity with other Proterozoic microfossils and modern marine microorganisms is striking. Tewari (2010, 2011, 2017a) 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 (Srivastava and Tewari, 2011). Astrobiology has now emerged as a distinct field of research where the possibility of extra-terrestrial life (Tewari, 2017a and references therein) is looked into. The Precambrian prokaryotes on Earth are used as analogues for such studies (Tewari, 2017a, 2019).

Cryogenic (glacial-fluvial and glacio-marine) conditions were prevailing during Permo - Carboniferous period in Lower Gondwana master basin of Peninsular India. Sedimentation in the basin was characterized by the massive to stratified diamictites in thin beds with alternate sandstone and shale (rhythmites) facies. Casshyap and Srivastava (1988) suggested the glacial - fluvial-delta environment of deposition in these basins from high uplift basement to low lying basin by tidal channels. The marine sediments were deposited in the basin of Mid-Continental rift system during the Early Permian through the North-Eastern rift system as a narrow seaway during Southern Tethys Sea transgressions (Valdiya, 1997, 2002). Tethys Sea was also penetrated from northwest direction towards Satpura basin to southerly region of Bap and Salt range. The record of typical marine invertebrates and ichnofossils from the Permo - Carboniferous sedimentary sequence of Gondwana Basins of Peninsular and Extra-peninsular India strongly suggest marine transgression during the Permian Period throughout the basin. (Wopfner and Casshyap, 1997; Singh, 1980; Valdiya, 1997). The Permo-Carboniferous sedimentary succession in the Lesser Himalaya is preserved in the form of Peri-Gondwana sediments across western to eastern part of Himalaya in the different state of India, viz. Kashmir, Himachal Pradesh, Uttarakhand, Sikkim, West Bengal, and Arunachal Pradesh (Figs. 10, 12, 13) (Tewari et al., 2022). The Permian transgression is well recorded from the Uttarakhand (Kumaon–Garhwal Lesser Himalaya), Indo -Nepal and Arunachal Lesser Himalaya in Eastern Gondwana which transgreesd over the Proterozoic - early Cambrian sediments of the Lesser Himalaya (Valdiya, 1988, 1997, 1998; Tewari, 1991, 1998, 2003, 2010, 2011, 2012; Tewari and Sial, 2007; Histon et al., 2013). The Phanerozoic sequence of Tethyan Himalaya in Kumaun, Garhwal, Himachal, Jammu and Kashmir is very well developed and interpreted as sedimentary deposits of the continental margin (Thakur, 1987). These sediments were accumulated in the basin due to tectonic upliftment of Lesser Himalaya in the early Paleozoic in a humid to semi humid climatic condition (Garzanti et al., 1996, 1998; Bhargava, 2000, 2011; Bhargava and Singh, 2022; Myrow et al., 2006, 2010; Jain et al., 1980, Kumar et al., 2020).

Isotopically light carbon has been recorded in the shales from lower Gondwana sequence of the Tethyan Sikkim Himalaya, India (Tewari et al., 2022). $\delta^{13}C$% (VPDB) from Gondwana shales range between -24.6‰ and -26.5‰. Total organic carbon (TOC) varies in these samples from 0.13 to 0.19. Isotopically light black shales have been recorded from the lower Paleozoic sedimentary sequences of North America, Europe and China (Meyers, 2014). The $\delta^{13}C$ of the Tethyan Gondwana shales recorded from the Sikkim Himalaya for the first time also show depleted values.

The larger benthic orthophragmine foraminifera assemblage of Lakadong Limestone is compared with Alpine- Adriatic - Himalayan –MeghalayanTethyan and Tibetan zones. The algal assemblage of Lakadong Limestone include Sporolithon sp., Lithophyllum sp., Jania sp., Corallina sp., and Distichoplax biserialis (Tewari, 2010a,b). The overlying Umlatodoh Limestone is characterised by larger benthic foraminifera of Thanetian - Ilerdian age (Fig. 18). Calcareous algae include species of Helimeda sp., Sporolithon sp., Ovulites sp. and Spongites sp., these larger benthic foraminifera and coralline algae show a wide biotic diversity in the Paleocene-Eocene eastern Tethyan carbonates of Meghalaya, east India and have been used in the paleobiogeographic reconstructions (Jauhri, 1979; Jauhri and Kumar, 2001). Global correlation and paleobiogeography of the eastern Meghalayan and western Tethyan Sea has been compared on the basis of SBZ of Paleocene- Eocene foraminifera assemblage. The similarities between NE India, NW Himalaya and Southern Tibet suggest that all these regions belonged to a single faunal province during Paleocene - Eocene period. Tethyan Himalaya persisted at the northernmost Indian plate, representing a passive continental margin until the end of the Palaeocene. Palaeozoic to Cretaceous marine sedimentary strata is widely exposed within the Tethyan Himalaya, whereas the Palaeocene-Lower Eocene shallow-water limestones developed mainly in the southern Tethyan Himalaya and Shillong Plateau, Meghalaya. (Hottinger, 1971; Tewari et al., 2010a,b, 2019, 2022; Lokho and Tewari, 2011, 2012; Sarkar, 2016, 2017; Jauhri, 1979). The paleobiogeographic reconstruction during Paleocene - Eocene times in the Western region shows its extension in the Eastern region. The index fossils of the Lakadong Limestone in Mawmluh Quarry section define the standard Paleogene biozones SBZ 3 and SBZ 5-6 respectively of Serra – Kiel et al. (1998). The biozones SBZ 3 and SBZ 4 present *Distichoplax biserialis* Dietrich, Miscellanea. The SBZ 5 and SBZ 6 contain Alveolina Hottinger, Nummulites sp. and Discocyclina sp (Fig. 18). The biozones SBZ 5 and SBZ 6 show *Ranikothali anuttalli* Davies).The mixed association nummulitids / assilinid and shell fragments encrusted by corallinacean algae are also found. The carbon and oxygen isotopic compositions of carbonate rocks provide useful information on paleogeography, palaeoclimate, and palaeoecology over geological times from Neoproterozoic (Tewari and Sial, 2007; Tewari, 2007; Tewari et al., 2008, 2009, 2011; Tewari, 2004, 2009a,b, 2012; Figs. 4, 5, 6, 7, 11) to Cretaceous - Tertiary boundary, India - Asia collision and subduction zone of Manipur Ophiolite belt (Figs. 16, 17, 19, 20, 21; Sial and Tewari, 2007; Sial et al., 2016, 2019; Tewari and Sial, 2014; Tewari et al., 2011; Tewari 2019, 2022; Singh et al., 2022). It is also considered that the diversity and distribution of benthic foraminifera in carbonate deposits of Manipur Ophiolite belt are excellent indicators in paleogeography, biostratigraphy, and palaeo-ecology of subduction related carbonates.

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