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Research Article

STRUCTURAL STUDIES OF THE MISHMI BLOCK IN PARTS OF DIBANG VALLEY OF ARUNACHAL HIMALAYA, NORTHEAST INDIA

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ABSTRACT
The least studied Eastern Himalya is tectonically a most vibrant block of SE Asia. The easternmost Indian counter part is represented by Mishmi block having three notable valleys-Siang valley to the west, Dibang valley in the central and Lihit valley in the easternmost part. Dibang valley of Arunachal Himalaya is constituted by Pleistocene river terrace, Proterozoic Roing gneiss, metasedimentary-metavolcanics of the Dibang Group, Miyudiya mafic and untramafic complex and Lohit granotoid complex from lower structural level (south) to higher structural level (north). Two major thrusts have been delineated – Mishmi Thrust between Pliestocene and Roing gneiss and Lohit Thrust between Dibang Group and Lohit Granitoid Complex (LGC). The complex lithological and structural map patterns portray the signature of polydeformed terrain indexing $D_1 – D_4$ where $D_1 – D_2$ are coaxial or nearly coaxial under simple shear mechanism. Mayudia syncline and Ithun anticline are the two major F_2 folds which control the present litho setting of the area and they are superimposed by F_3 nearly at right angle to F_2 fold axial orientation resulting dome and basin structure. Most of the F_2 folds on minor scale are showing top to the south vergence.

Absence of Tethyan sediments in the Dibang valley, absence of radiolarian chert in associated metasedimentaries, limestone without microfossils, non cummulate nature of the ophiolite, northward dextral movement of the western Arunachal Himalaya around Bame fault and truncation of the Indo-Myanmar mobile belt at Mishmi Thrust with left lateral vergence, are the characteristic features which probably indicate that the Mishmi block is not a continuation of Western Arunachal Himalaya rather favours as a foreign block from Myanmar plateau tectonically emplaced as a roof over the two pillars like Indo-Myanmar mobile belt to the south east and Western Arunachal Himalaya to the west.

Key Words: *Mishmi Block, Syntaxial Bend, Arunachal Himalaya, Dibang Valley and Ne India*

INTRODUCTION
Most of the orogenic belts of the world have undergone a complex history of noncoaxial polyphase deformation resulting restructuring, recrystallisation and reorientation of earlier fabrics. The loftiest Himalaya exhibits a curvilinear disposition extending over a length of about 2500 km from western syntaxial bend at Nanga Parbat (33^{0}15'N:74^{0}36'E) to eastern syntaxial bend at Namche Barwa (29^{0}37'N:95^{0}15'E) and owes its existence due to continent-continent collision of the Indian and Eurasian plates. Upper and Lower Dibang and Lohit and Anjaw districts of Arunachal Pradesh, cover the hinge zone of the high hilly terrain of Arunachal Himalaya. This hinge zone is traditionally named as Mishmi block (Thakur & Jain, 1974; Nandy, 1976; Singh & Malhotra, 1983), which practically rests like a tectonic roof or tectonic umbrella (Sarma *et al.*, 2009) or tectonic linkage (Nandy, 1981) over the two flanks like E-W trending Eastern Himalaya (EH) to the west and NNE-SSW trending Indo Myanmar Mobile Belt (IMMB) to the southeast; the latter abut against the former. Thus, confusion persists on the Mishmi block (erstwhile Lohit Himalaya of NEFA of undivided Assam) of the NE Himalaya over a long time regarding the existence of eastern syntaxial bend. It is a site of International junction between China to the north, Myanmar to the east and India to the south. The generalized lithogroups and their lithocomponents, orientations, metamorphism of the western sector of the Arunachal Himalaya (AH) from Bhutan up to west of Siang district (Bame fault), are almost identical, but it seems they do not continue further east up to Siang, Dibang and Lohit valleys (eastern Part of Bame fault). The generalised

trend of western AH is roughly E- W but deviated towards north along N-S trending Bame fault. The NW-SE trending lithotrend of the Mishmi block truncates the Bame fault along the western part of Siang-Tuting valley. Singh and Chowdhary (1990) have suggested that the lithounits of EH are deflected around the Siang valley (Siang dome). Chattopadhyay and Chakraborty (1980) have suggested that the granite granodiorite complex and the Tidding serpentinite of Lohit Himalaya are intrusive into the enveloping metasediments and therefore, any thrust between them is doubted. Question arises whether Tuting Tidding belt is a true ophiolite belt (Sinha Roy and Singh, 2002)? It is not identical to either Tsangpo ophiolite or Naga Manipur ophiolite; rather it is a hybridized Paro group with granodiorite batholith and basic intrusive (Acharyya, 1978). Dhaundial *et al*. (1976) have suggested the presence of a late Cenozoic thrust at the western boundary of the Mishmi Hills plutonic complex above the imbricated low to high grade metasediments intercalated with isolated occurrence of serpentinite and mafic ultramafic rocks, the latter was designated by Thakur (1998) as dismembered ophiolite. Burg *et al.* (1998) finally synthesizes that the western boundary of the Mishmi block is continuation of the Tethyan Yarlung Tsangpo suture. They have suggested that the eastern syntaxis resembles the evolution of the western Himalaya syntaxis in Pakistan and metamorphic rocks derived from India occur structurally below the suture and the core of the regional Namcha Barwa antiform. However, the way Nanga Parbat of western Himalaya portrays a significant and well established syntaxial bend; the eastern syntaxis is in a state of confusion wheather its position is in Tibet or in India. Singh (1993), Singh and Chowdhary, (1990) and Thakur and Jain (1975) claim that Eastern syntaxial bend is located around Siang valley as 'Siang antiform". Thakur and Jain (1974) initially suggested as the hair pin bend of Arunachal Himalaya which merge into Indo-Myanmar mobile belt. On the contrary Burg et al. (1997) claim that eastern syntaxial bend is located at Namcha Barwa of Tibet. This aspect needs further explanation.

Mishmi Block virtually receives no attention mainly because of its inaccessibility, remoteness, hostile climate, dense vegetation and sparsely distributed population pattern. Confusion also prevails relating to Mishmi gneissic complex / Lohit granite- granodiotitic complex. Are they intrusive into metasedimentary sequences? Are they deformed and metamorphosed? Can they be treated as multiple intrusion cycles separated in space and time and tectonically thrusted over the metamorphites? Can the Dibang Group be equivalent to the central crystalline complexes of the Higher Himalaya? Can we believe and consider that the entire Mishmi block is a continuation of western part of Arunachal Himalaya? These are some of the notable queries. Tidding serpentinite is considered as intrusive into metasediments and the litho association of the Mishmi block is considered as Tidding suture (Nandy *et al*, 1975; Nandy, 1980) and correlated with the Mogok belt of Burma (Goosens, 1978). Tidding suture seems to have no continuation with Tsangpo-suture to the west. Neither have they had genetic relationship with the Manipur-Nagaland Ophiolite complex of the NE India. Ghosh and Ray (2003a & b) studied the Dibang Valley section and detail mineral chemistry of the rocks of Mayudia –Hunli area has been worked out. They have suggested that ophiolites of the Mishmi block falls in the extrapolated eastern end of the Indus belt. They have further suggested that subduction related tectonic settings might have played an important role in the emplacement mechanism of such ophiolites which have a deeper geotectonic status specially related to collision of Indo-and Tibetan block during closure of the Tethyan Ocean in Meso- early Tertiary times (Searle and Cox, 1999). Ghosh and Ray (op.cit) suggested that the different litho units of the ophiolite show affect of progressive metamorphic reconstitution from very low grade to medium / high grade from top downward.

Rajesham and Dutta (1983) have established multideformational events (F_1, F_2 and F_3) imprinted into the rock association of the Dibang Valley. Burhanuddin and Nandy (2004) have mapped the Dibang area and identified two major folds as Ithun antiform and Mayudia synform, which control the lithosetting of the area and they have suggested a most reliable stratigraphic succession with the incorporation of Dibang Group (=Mishmi Group of Thakur and Jain, 1975).

Gururajan and Choudhuri (2003) have studied the Lohit valley of eastern Arunachal Himalaya and set four tectonic units namely Lesser Himalaya, Mishmi Crystalline, Tidding suture zone and Lohit plutonic complex. Delineation of thrusts, establishment of chlorite to staurolite/ kyanite zone exhibiting inverted metamorphism and their correlation to deformation are some of the salient features listed as an extension of the works of Thakur and Jain (1975). Geochemistry of the rocks of Trans Himalayan plutonic complex is studied in detail and suggested probable genesis and multiple intrusion cycle ranging from gabbro, diorite**,** trondjhemite to leucogranite (Gururajan and Choudhuri, 2007). Choudhury *et al*. (2009) have further synthesized the geology and structural evolution of Arunachal Himalayan syntaxes. Sarma *et al*. (2009) have studied the Mishmi Block along Dibang and Lohit valleys and suggested a few observations on the eastern syntaxial bend along with a tectonic schematic model regarding the lithotectono stratigraphic configuration of the Mishmi block.

The present authors have taken Dibang valley traverse along Roing-Mayudia-Hunli-Anini road of Upper and Lower Dibang districts of Arunachal Pradesh and attempted to establish a structural framework of the block along with a possible tectonic model. Lithotectonic stratigraphic sequence of the western Arunachal Himalaya whether can be correlated with the lithosequences of Dibang valley is another aspect to be dealt with in this communication.

General geology

Lithostratigraphic framework of the NW-SE trending Mishmi Block is worked out from the Dibang valley traverse, along Roing-Mayudia-Hunli-Anini geotransects of Upper Dibang and Lower Dibang districts. The sequence includes Pleistocene River Terrace (PRT), Proterozoic Roing Gneiss (PRG), metavolcanosedimentaries of Dibang Group (DG), Mayudia mafic- ultramafic complex (MMUC) and Lohit granitoids complex (LGC).

Pleistocene River Terrace (PRT): In this geotransect Pleistocene river terraces are exposed at 1km north of Roing along Deopani River and mark the southern limit of Pliestocene lithounit**.** It extends about 8 km along Roing-Anini road almost across the lithostrike and they are thrusted over by Proterozoic augen gneiss in Dibang valley. This tectonic contact is marked by Mishmi thrust ($27^0$52’11” N: $96^0$21’1”E). No Siwalik and Gondwana Group of rocks are observed in Dibang valley. Choudhury *et al*. (2009) confirm that Siwalik and Gondwana Group of Siang sector are cut off by the Mishmi thrust or MBT in Dibang sector.

Proterozoic Roing Gneiss (PRG): Biotite gneiss, augen gneiss, thinly bedded amphibolite and quartzite are the main lithocomponents of the PRG in Upper and Lower Dibang Valley districts. They are highly deformed showing evidences of ductile shearing. The feldspar augens are rotated both clockwise and counterclockwise and make 10^0 to 30^0 with respect to the direction of tectonic flow (NW-SE), deflecting round the rigid feldspar augens. Ribbon structure is common, augens are partly faulted in a reverse direction. Associated amphibolites are thinly bedded, medium grained well schistose and boudinised at lower structural high where as the above sequence is dominantly exposed in the Ithun river section and confined in the core part of the major Ithun anticline (Burhanuddin and Nandy, 2004; Nandy *et al*., 2005, Sarma *et al*., 2007).

Dibang Group (DG): Metasedimentary and metavolcanic rock associations unconformably overlying the gneissic belt are designated as Dibang Group. The thickness of DG in Dibang valley is almost double the adjacent Lohit Valley to the east. They are divisible into two distinct stratigraphic units- metavolcanic Ithun Formation and metasedimentary Hunli Formations (Burhauddin and Nandy, 2004). The Ithun Formation is well exposed along the Ithun river valley upto its confluence with the Dibang river and further southwest towards Rayalli Village. Metabasites (amphibolite, hornblende schist and actinolite-chlorite schist) are intercalated with quartzite bands of varied thickness. The Hunli Formation comprises of alternating layers of metapelitic rocks, quartz-chlorite $\pm$ actinolite schist, carbonaceous phyllite, garnetiferous phyllite and intercalation of limestone. Hunli Formation conformably overlies the Ithun formation. This Formation seems to be lateral equivalent of Tidding and Yang Sang Chu Formations (Nandy, 2004). Compact limestone bands are traced at many places (SW of Hunli, Arzu, Endolin and near Rayalli).

Mayudia Mafic- Ultramafic Complex (MMUC): The Mayudia mafic-ultramafic complex represents a sequence of layered ultramafics (peridotite / serpentinite), coarse-grained pyroxenite, hornblendite, dunite and basic schist. They are intercalated with chert, mafic dykes/sills, carbonate rocks and leucogranitic veins. The mafic and ultramafic bodies occupy the core of the Mayudia synclinal structure over a width of more than 10 km in the Mayudia hill ranges. The rocks are hard, compact, dense, and greyish to greenish black in colour and show bouldery as well as in layered form. They are mostly sheared. Serpentine bears the evidence of stretching lineation, striation, more shinning and polished showing network fabrics. Anastomosing foliation, rough and pitted structures and lenses in the form of discontinuous blocks or sheets are very common features. The ultramafic rock shows radiating fabric like sphinifex and pillow structure near the Mayudia Pass and Ardzu. A hornblendite dyke is seen around Mayudia Tourist lodge transecting lithosetting at low angle. Isolated bodies of ultramafics near GB Ghar, north of Ardzu, Tidding, and near Rayalli are comparatively more serpentinised than the Mayudia outcrop. The schistose basic assemblages are represented by basic volcanics/ tuff with thin intercalations of chert, mafic and felsic dykes/sills. Ultramafics are found as small lenses, enclaves within augen gneiss. Thickness of this mafic-ultramafic lithounits of Dibang valley gradually decreases towards adjacent Lohit valley**.** On the other hand, MMUC whether is continuing further south east along Tezu-Hayuliang-Walong geotransect is doubted. Tidding metavolcanics may be either a counter part of Ithun formation or there are two phases of mafic utramafics expulsion, one being tectonically dismembered.
Lohit Granitoid Complex (LGC): Huge occurrences of intrusive diorite –granodiorite**-** tonalite and granite masses associated with high-grade gneissose / schistose assemblages are designated as LGC by earliar workers. This NW-SE trending monotonous body is also named as Mishimi massif or Mishmi granitic – granodioritic complex (MGGC), thrusting over the metavolcanics and metasedimentary components of the Dibang Group. This thrust is conventionally named as Lohit thrust by early workers. The granite is leucocratic comprising of quartz, feldspar, hornblende and biotite as dominant mineral phases. The tongues and apophyses are clearly seen. The rock is schistose, pulverized, mylonitised and is supposed to be thrusted over the metasedimentaries of DG as Lohit Thrust (Nandy *et al*., 1975). Highly folded faulted gneiss are seen after metasedimentovolcanic sequence towards higher structural level in Dibang valley. They are associated further north by Lohit granitoid. Tuting metavolcanics are seen which probably marks the interface between LG and gneisses. Similar observations are seen in the southeastern strike continuity around Desali (Rajesham and Dutta, 1983). The thickness of the LGC is more in Lohit valley as compared to Dibang valley. In reality, the southern boundary of the granitoid is closely associated with banded gneisses of acidic and basic composition in both geotransects. It is probable that the asssociated gneisses belong to Proterozoic and are intruded by Lohit granitoid. Detailed field based observations and geochronology may throw some insights into the problem, whether Lohit Thrust is located between gneisses and metavolcanosedimentary units or between LGC and DG.

Structural History

The rocks of the Dibang valley are affected by four phases of deformations (D_1 to D_4) in the eastern part of the Arunachal Himalaya (Nandy, 2001) Phase wise deformational interpretations and their interferences as are not delineated by earlier workers, hence, a systematic integration of bedding /stratification, foliation, lineation, folds and faults has been attempted to ascertain the structural architecture of the Mishmi Block along Dibang valley.

Imprints of intensive deformational impacts over the different lithotectonic units, remobilisation of Indian Proterozoic basement followed by upliftment or thrusted dismembered tectonic units or slices over the younger sequences are some of the classical documents portrayed by the Great Himalayan Orogenic Belt (GHOB). A wide spectrum of geodynamic architecture is manifested by several thrusts such as Main Central Thrust (MCT), Main Boundary Thrust (MBT), Main Frontal Thrust (MFT), South Tibetan Detachment System (STDS) and number of thrust bound lithotectonic units like Sub Himalayan sequences (Outer Himalayan = Siwalik Himalaya), Lesser Himalayan Sequences (LHS), Higher or Greater Himalayan sequences (HHS, also named as Himadri), Tethyan Himalayan sequence (THS) and

Trans Himalayan Batholithic sequences (THBS) in western, central and western parts of Arunachal Himalaya. But such tectonic impact is doubted in eastern part of the Arunachal Himalaya i.e. in Mishmi Himalaya. Recently, Sarma *et al*. (2011) have discussed the thrust bound architecture of the Arunachal Himalaya and suggested that the conventional MFT, MBT, MCT and THT is to be re looked into and thrust tectonics of the Western Arunachal Himalaya is not continuing and correlatable with Eastern Arunachal Himalaya.

Deformational episodes

The complex lithological and structural map patterns portray the signature of polydeformed terrain (Fig. 2). Many people believe that the Mishmi Block also screens the India-Asia plate collisional tectonic imprints during Cenozoic time. The structural architecture of the northward subduction of the Indian plate beneath the Asian plate led to the development of intracontinental crustal shortening, restructuring and remobilization during the Himalayan orogeny and hence, in Western Himalaya most of the authors favour two-fold classification of structures namely under (a) Pre-Himalayan deformation and (b) Syn Himalayan deformation (Jain *et al*. 2002 and a number of authors cited therein). They have further referred to that the Himalayan Metamorphic Belt as a whole has undergone four phases of recognizable deformations (D_1 to D_4), out of which D_1 appears to be Pre-Himalayan and D_2 to D_4 during Himalayan orogeny. But Sharma (2005) suggested that the conventional Lesser Himalayan Crystalline and Higher Himalayan Crystallines were initially the Precambrian crystalline rocks of the Indian plate and modified during Himalayan orogeny. Hence, polymetamorphic and polydeformed aspects of the basement rocks of the Himalaya require rethinking.

Highly deformed stratified sequences of mafic and ultramafic rocks are probably the products of transposition of initial layering due to layer parallel shear couple. In associated quartzite cross stratification and ripple marks are still preserved. The initial configuration of primary bedding is probably lost or restructured due to deformational impact in subsequent geologic time. Some of the mafic dykes are observed near Mayudia Pass and north of Lohit Thrust near Angolin and they cut across NW-SE trending litholayering at high angle in NNE-SSW direction. Pillow structure is found near Mayudia pass and between Ardzu and Rayalli. Amygdular basalt representing another primary structure between Lohit Thrust and Dibang Group seems to be lateral extension of Tuting metavolcanics and are highly strained in the direction of tectonic transport.

Minor Structures

First phase of deformation (D_1)

The earliest recognizable deformation (D_1) is traceable in augen gneiss, its associated quartzites, amphibolites and other metavolcanics. The present stratified sequences were probably deposited in a near horizontal setting and finally transposed into intensive foliation cum litholayering and acts as basement of Pre-Himalayan orogenic phase. Tectonically sheared out, rootless, isoclinal F_1 folds enclosed within ductile host with attendant S_1 foliation is a supporting evidence of Pre-Himalayan orogeny. During Himalayan orogeny they were extensively sheared resulting CS_2 planar fabric on regional scale. Minor F_1 folds showing dextral pattern (Figs. 1 a, f) are well preserved in augen gneiss at 10 km post from Roing and also in the core of Ithun anticline around Sukla Nagar. The aspect ratio of F_1 fold varies and accordingly more is the tightness high is the aspect ratio. The folding angle (ϕ) of F_1 varies from 160^0-180^0 whereas in metasedimentary and metavolcanic units, it varies from 130^0-160^0 (tight to close type). S_1 is axial planar to F_1. The intrados curvature of F_1 is greater than extrados curvature ($i > e$) plunging towards NE and /or SE direction at moderate angle ($<60^0$). Occasionally, F_1 shows top to the SW vergences. Layer oblique fractures in F_1 fold sometimes indicate convergent pattern.

Lithological layering (S_0) and shear foliation of second deformation (CS_2) parallels to S_1 and is considered as a reference surface to work out the regional structural configuration. The generalized trend of S_0 ($=S_1=CS_2$) foliation is NW-SE although there is a deviation from NNW-SSE to almost E-W showing dip either towards NE or SW at moderate to high angles. L_1 is preserved in the core part of the Ithun anticlinal zone and they are mostly marked by fold axes, intersection of $S_0 \wedge S_1$, stretching lineation, pinch and swell structures, fold mullions and boudins (Fig. 1a, h).

Second phase deformation (D_2)

D_2 deformation controls the regional configuration of the lithological layering followed by development of most pervasive shear foliation (CS_2) during Himalayan orogeny and consumes most of the earlier structures. Axial orientation of F_2 folds varies from NNW-SSE to NW-SE direction and is mostly coaxial with F_1 showing moderate to sub vertical plunge. F_2 is of upright to recumbent through tight with characteristic right and left lateral asymmetric vergences (Fig.1c). In some cases F_2 minor folds are mistaken as F_1 because of their similar style and geometry but the former bear evidences of earlier S_1 foliation preserved at the hinge and CS_2, being axial planar to F_2, maintain crosscut relationship at high angle. Intensive shearing during D_2 deformation results CS_2 (C-S foliation) along axial planar orientation of F_2 and therefore, on the outcrop scale, S_0, S_1 and S_2 are parallel or near parallel to each other and regional NW-SE trend defined as x-direction of the strain ellipsoid or direction of tectonic transport during Himalayan orogeny. 'S' shaped F_2 folds indicate top to the SW sense of shear (Fig. 1h). Minor faults are observed and they transect F_2 folds at a high angle (Fig. 1g). Axial plane fracture cleavage (CS_2) is seen in the competent rock. The gneissic foliation of the augen gneiss swerves around the basic enclaves and the latter registered the earliest foliation (probably S_1) sometimes parallel to the host rock or makes different angle with the matrix (CS_2). In the mesoscopic folds, CS_2 is curviplanar due to interference of later deformation. F_1 is refolded by F_2 folds (type 3 interference pattern of Ramsay, 1967) and the former represents a relict of basement of Himalaya. L_2 is mostly marked by stretching lineation.

Third phase deformation (D_3)

F_3 folds developed on microscopic to mesoscopic scales vary from millimetre to tens of meter. Wavelength (λ) varies in crenulations from 2.5 cm to 8 cm and amplitude (A) from 2 to 5 cm in average. The trend and plunge of F_3 vary from N30^{0}E to N50^{0}E at low to moderate angle (20^0-50^0). They are asymmetric with top-to-the-west shear sense. Upright nature with near vertical axial plane and near horizontal plunge ($\cong 10^0$) due NE to NNE is observed in most of the metasedimentary and metavolcanic units. The interlimb angle and wavelength/amplitude ratio are highly variable and such variation depends upon the competency of the rock. They are mostly of similar type (class 2) particularly in the incompetent rock with thickening hinge and thin limb while in more competent rock; both similar and concentric types are seen. Down dip plunge with near vertical axial plane is seen in phyllitic rocks. Enechelon fold is common in metapelites. Interference of F_2 and F_3 is manifested (Fig. 1b). Here L_2 is deflected from F_3 fold axes with anticlockwise vergence. A few F_3 fold profile sections are prepared and analysed by dip isogon method and plotted in computer using the software "Geometry of folded layers" formulated by P.P.Roday. Most of the plots are fallen in the 1C and 3 indicative of modified similar and modified parallel types.

In some cases, F_3 and F_4 structures are so similar that it's become difficult to ascertain whether they are the product of two different phases of deformation. Dip of axial plane and their orientation also do not show notable variation. In such cases they could be considered as early and late stages of the same D_3 deformational episode under simple shear mechanism in the crustal shortening process. Mukhopadhyay *et al.* (1997, 2010) also advocated such type of observations from Indian Peninsula but from Himalayan belt no such report is available in specific. S_3 is a non pervasive planar structure developed occasionally along the short western limbs of small scale folds or along strain zone sub parallel to the axial plane of F_3. In the schistose rocks like graphitic mica schist, chlorite actinolite schist and phyllite, crenulation cleavage (S_3) is characteristically developed. Recrystalised micas forming CS_2 is bent by F_3 open asymmetric fold. Such S_3 either destroy S_1/ CS_2 fabric or reoriented the earlier planar fabrics. L_3 lineation includes minor fold axes, crenulations, intersection lineation, mineral lineation and rarely rod lineation in case of metapelites. Interference between F_2 and F_3 (Fig. 1h) is common throughout the area compared to F_1 and F_2 interference (Fig. 1f). Sense of asymmetry is also noted from the different limbs of the major folds, leading to the development of S and Z sense of rotation. The interference between F_2 and F_3 is seen in the microstructural level.

Fourth phase deformation (D_4)

D_4 is marked by kinking, faults, joints and fractures on different scales and the orientation is mostly restricted in and around N-S direction. This phase is demonstrated by Jain *et al*. (2002) in the form of culmination and depression on large scale in the western Himalayan belt showing open and upright geometry. They have further advocated that D_4 is largely a post kinematic phase to the major thrust system. In case of Arunachal Himalaya, Kumar (2001) claims that F_4 is of warp type and related to eastern syntaxial bend. Eastern syntaxial bend and Siang antiform might have developed during D_4 deformation as stated by GSI (2010).

Figure 1:

A: Tectonically sheared out feldspar augens with dextral movement. Quartzo feldspathic vein display Z-pattern of nearly isoclinal fold in augen gneiss. Location: at 8 km post. Diameter of the coin is 2.2 cm.

B: Carbonaceous phyllites showing enechelon pattern of folding with down dip plunge. Lineation across fold axis is observed. Location: 65 km Nandan Pass. Size of the pocket lens 4 cm long.

C: Asymmetric folding with top to south vergence facing SE at the Mayudia Hill Complex.

D and E: Rocks of Dibang Group at Ithun river bridge point show opposite dips SW and NE in photographs respectively indicating Ithun anticlinal structure.

F: F_1 fold marked by quartzite layer with low angle plunge towards NW affected partly by open F_2 fold from Shukla Nagar area.

G: Highly sheared banded gneiss showing interference of folding. Minor faults are observed. Location: near Lohit Thrust.

H: Low grade phyllitic rocks with embedded quartz lenses showing folds of two generations (F_2 and F_3). Folds are showing top to SW vergence. Location: near Hunli.

I: Intensive quartz veining in migmatites from Lohit Granitoid Complex.

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Research Article

Major structures

Lithological layering (S_0) and attendant foliation (S_1) to F_1 folds are subsequently deformed by intensive D_2 deformation resulting pervasive CS2 foliation on regional scale. Mayudia syncline and Ithun anticline (Fig. 2) are the two regional fold structures observed in the area. Crustal shortening of the Indian plate at the convergent boundary may be the cause of such large scale folding during Himalayan orogeny. F_2 folds are deformed by F_3 during Himalyan orogeny and hence, the present regional structural architecture is controlled and modified in totality by second and third phases of deformation.

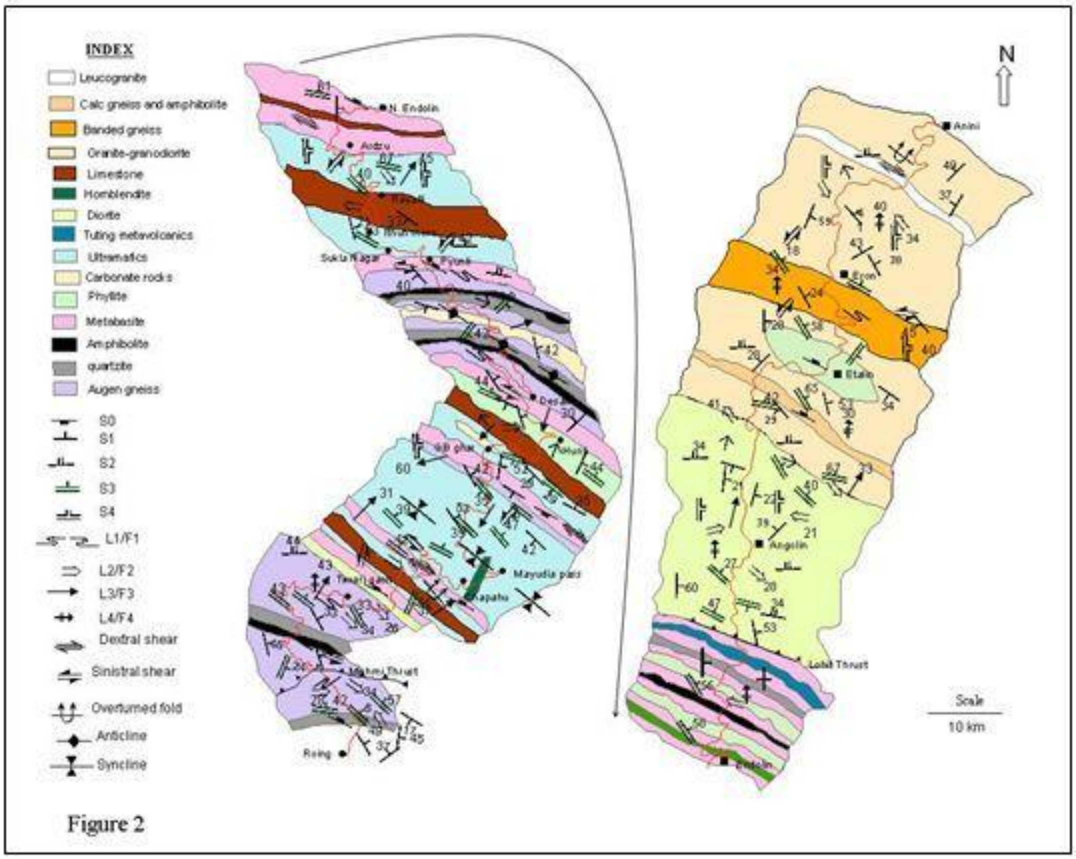

Figure 2: Structural and lithological map of Dibang Valley, Mishmi Block Arunachal Himalaya

Mayudia synclinal structure

Mayudia synclinal structure measures about 40 km across the regional litholayering in a roughly NNE-SSW direction. On the southern or southwestern flank of the syncline all schistose rocks and their associated foliation show north to northeasterly dip, at gentle to moderately steep angle (Figure 2, 3a). The northern flank is short and steep; dip varies from 40^0-75^0 due SW. Sense of asymmetry of minor folds show top to the south vergence. The northern limb of Mayudia syncline is the southern limb of Ithun anticlinal structure (Figure 2, 3b). The litho profile section is shown in Figure 3a, b, c and plots of the poles of planar and linear structures are shown in figure 4.

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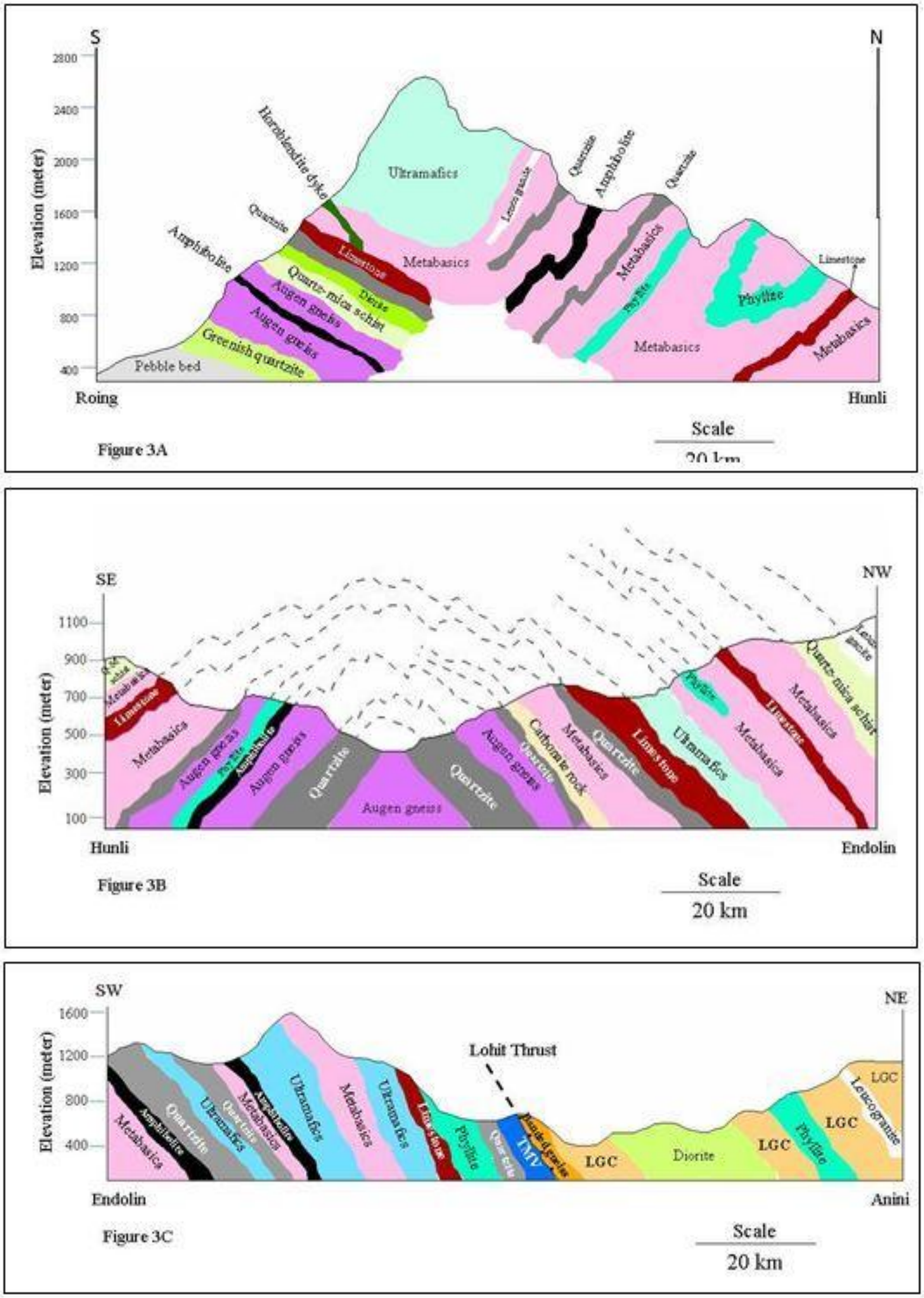

Figure 3: Three sections from Roing to Anini of Dibang Valley Districts (reference figure. 3):
A: Cross section from Roing to Hunli; B: Cross section from Hunli to Endolin; C: Cross section from Endolin to Anini

For statistical analysis the entire fold area is divided into sectors and sector wise minor structural elements are analysed using GEOrient software. The geometrical pattern of planar and linear fabric have been analysed sectorwise and plotted the structural data in lower hemisphere equal area projection diagram. From south western limb of Mayudia suncline, plots of the poles of CS_2 foliation (S_1=S_0) when contoured clearly indicate a spreading symmetric pattern with β_{CS2} axis at 39^0 towards 019^0 (NE). Similarly, plots of the poles of CS_2 from northeastern limb show elongation pattern with a prominent β_{CS2} axis at 60^0 towards 198^0.

Statistical mean plots of minor crenulation axes / lineation coincide with the β-axis of the plots of the planar fabric (Figure 4).

Planar fabrics of D_3 deformation and their associated fold/lineation fabrics are also plotted in the stereonet and their concentration is seen mostly in NE and SE quadrants. The traces of the axial surface are curvilinear varying from ESE to SE. The hinge zone passes through Mayudia pass and attitudes of the litholayering on both side changes from moderate to low angle dip towards Mayudia. Basic intrusives maintain discordency with the country rock. The fold profile indicates that the D_2 deformation was mainly under NE-SW compressive stress with little variation towards N.

Ithun anticlinal structure

This structure occupies the Ithun river section along WNW-ESE direction. The Ithun river flows towards WNW and merged into N-S trending Dibang River. The closure of the anticlinal structure is observed towards east of Ithun bridge. The core of the anticline is occupied by Proterozoic augen gneiss, amphibolite and quartzite mainly. The southern limb of the anticlinal structure is dipping SW at moderate to steep angle while the northern limb dips towards NE at moderate angle. Planar and linear structures from both the limbs are shown in figure 2. The southern limb of the Ithun anticline is the northern limb of

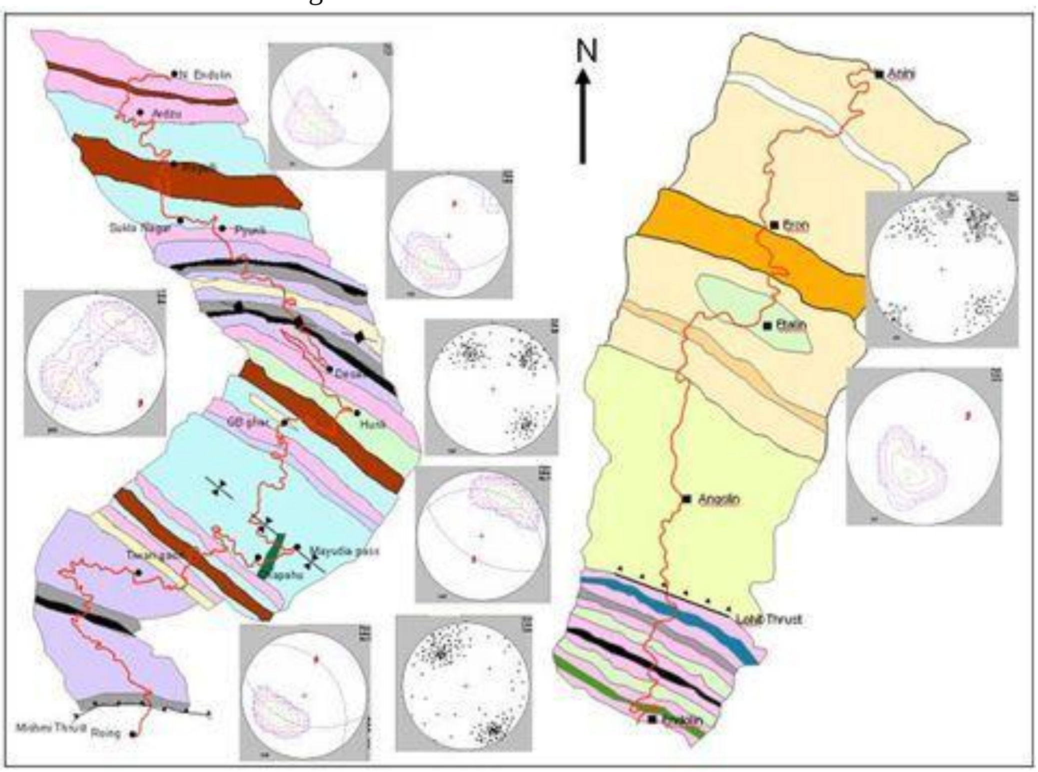

Figure 4: Lower hemispheric equal area projections of planar, linear and fold structures are shown in the lithological map

Mayudia syncline. Tightness of the folds shown in profile section gradually increases towards north and as such the presence of large scale structure beyond Rayalli (towards Endolin) can not be ruled out. No large scale overturned or isoclinal folds are traceable and most of the minor F_2 folds are showing top to the south shear sense. The anticline is an asymmetric plunging fold with curvilinear fold axis varying in

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direction from NW-SE to SW-NE. Such variation is due to superposition of F_3 folding and the trend line of F_2 major folding also show culmination and depression i.e. dome and basin structure (type 1 interference pattern). Large scale dome and basin structures are not traceable and it is probably because of thick forestation, snow cover and inaccessibility in most of the parts. Tidding River of the Lohit and Anjaw districts to the east of the study area is flowing from NW to SE and merged into Lohit River. In Dibang Valley district, generalised orientation of the Ithun River is NW-SE and the river is flowing from SE to NW, and merged into N-S trending Dibang River. Both Tidding and Ithun rivers are probably originated from a very high structural level and the source area might be a domal structure.

Kinematic interpretations

On the northern limb of the Ithun anticline, augen gneiss and metasedimentary rocks are observed as close associates and show partial migmatisation and lit per lit injection of quartzofeldspathic veins. Gneissic foliation and banding as well as pervasive CS_2 are parallel to each other and hence it may be suggested that the emplacement of the protolithic body of the augen gneiss is pretectonic to D_2 deformation and related to syn D_1 episode. Stretching lineation is parallel to subparallel to the axial orientation of the regional F_2 folds i.e. mostly SE with subhorizontal to low plunge. The development of major structures is initiated in a compressional regime and such possibilities may be substantiated with the growth of stretching lineation parallel to the axial orientation of small scale structure to the major fold structure. It is also probable that the entire lithounits of the study area have undergone thorough recrystallisation in different phase's i.e. pretectonic, syntectonic and post tectonic to Himalayan orogeny. Basic and acidic intrusive were initiated during and after D_2 phase.

Considering all the observation an attempt has been made to interpret the kinematics of the large scale ductile shear zonal lithopackage of the Dibang Valley. The subhorizontal attitudes of mylonitic foliation or S-C fabric with south easterly dipping (~10^0 to 30^0) stretching lineation and top to the south vergence thrusting movement during syn Himalayan orogenic episode, may be responsible for upliftment of the mafic ultramafic units to the surface from deeper structural level.

DISCUSSION

The thrust bound orogeny parallel lithopackages of Dibang Valley geotransect start with alluvium/Pleistocene river terraces followed by Proterozoic augen gneisses, metamorphites of the Ithun and Hunli Formations of the low to medium grade Dibang Group, Mayudia mafic and ultramafic and finally LGC from lower structural level (south) to higher structural level (north).

The different tectonic imprints of the Mishmi block are correlated with the tectonic setup of the Himalayan orogenic belt by some authors and hence Pre-Himalayan, Syn-Himalyan and Post-Himalayn terminologies are made use of. Broadly, first (D_1) and second (D_2) phases of deformations are coaxial to nearly coaxial under simple shear mechanism and D_3 and D_4 deformations are superimposed over the earlier phases nearly at right angle. Mayudia syncline and Ithun anticline are the two major fold structures developed during Himalayn orogeny. D_2 with axial orientation NW-SE superimposed by D_3 deformation with NE-SW orientation resuting dome and basin structure (type 1 interference pattern). Presence of a large scale domal structure is postulated but could not be traced due to physical hindrance (mainly snow cover, deep forestation and in accessibility). A possible zone of structural high representing a large domal structure is indicated between Lohit valley and Dibang valley where from both Ithun and Tidding rivers are originated and flowing in two opposite directions NW and SE respectively. Proper geomorphological approaches and satellite imagery interpretations if undertaken probably the location of such structural dome (high) could be ascertained. Metamorphism increases with increasing structural height and as such inverted metamorphic signatures are observed and rocks have witnessed metamorphism under garnet to staurolite kyanite zones belonging to greenschist to middle amphibolite facies (Sarma *et al*., 2009).

Thrust bound architectures of Arunachal Himalaya is attempted by Sarma *et al*. (2011) and they have referred to that WAH bears a true Himalayan signatures which are the lateral extension from western Himalaya through Nepal, Sikkim and Bhutan Himalaya upto the Bame fault but eastern Arunachal

Himalaya does not reflect such thrust system rather conventional and classical Lohit thrust and Mishmi thrust are made use of in literatures. As there are a number of thrust noted by different workers such as Roing thrust, Tezu thrust, Sewak thrust, Lalpani thrust, Mayudia thrust, Tiddding thrust, Wallong thrust etc. hence, they have equated (not continued) all these thrusts with the classical MFT, MBT, MCT applicable in case of Mishmi Block.

The Mishmi orogenic belt lying between Eurasian plate to the north and Indian plate to the south is a highly linear belt of NW-SE extension which practically rest like a roof on the two pillars like Western Arunachal Himalaya to the NW and Indo-Myanmar mobile belt to the SE. The generalised lithology and trend of the Arunachal Himalaya is roughly E-W and deviated further towards N-S along right lateral Bame fault (Tuting-Igo fault of Singh, 1993) truncating NW-SE trending Mishmi block at SE of Namche Barwa. Dibang valley geotransect and Lohit valley geotransect are the two important geotransects in the eastern part of the Mishmi block while Siang valley geotransect represents the western part of the Mishmi block. Taking into consideration of all the three blocks, Sarma *et al.* (2009) have noted that apart from E-W trending WAH which veers towards north with a right lateral motion along Bame fault, the IMMB to the east also truncates at the Mishmi thrust and rotated in clockwise direction towards Myanmar, thus showing top to the west sinistral movement of the Mishmi Block. Therefore, the clockwise motion of the IMMB and counterclockwise rotational movement of the Siang antiformal structure portray the movement kinematics of the Mishmi block.

Nandy (2001) has suggested that EAHB or MB is a separate thrusted geounit transported from Mogok belt of Burma. The investigated area forms an irregular and relatively narrow (~300 km long) nonlinear S-shaped traverse along Roing – Mayudia – Hunli – Italin – Anini geotransect which is roughly parallel to the Dibang river valley of Arunachal Himalaya. Relating to tectonic configuration of the Mishmi block, a tectonic schematic diagram is suggested (Figure 5).

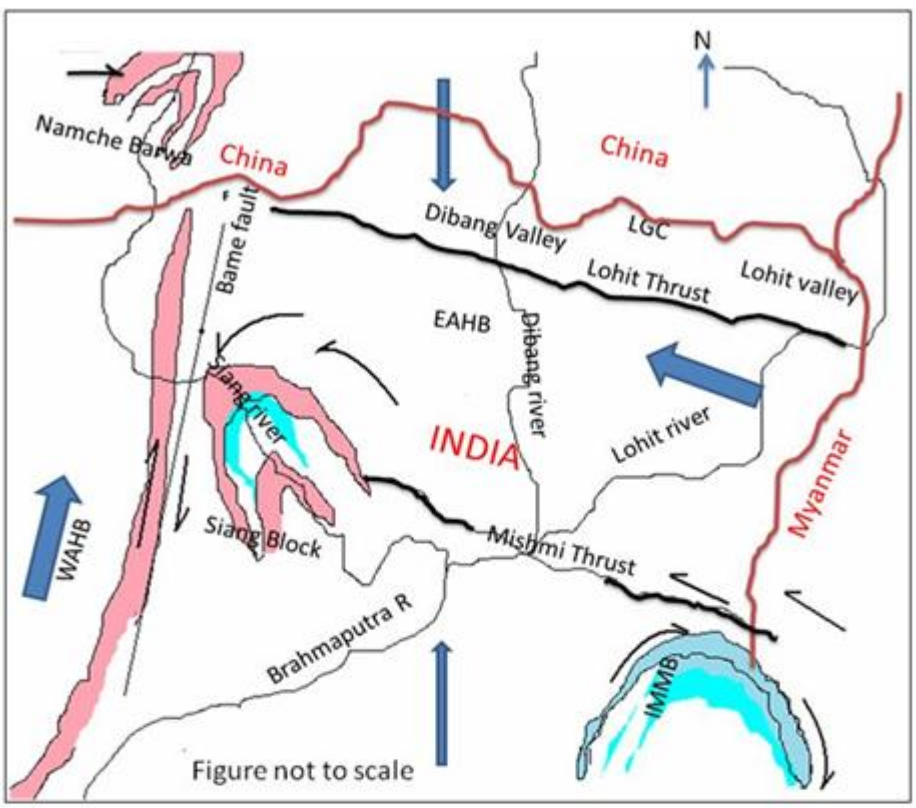

Figure 5: Tentative tectonic model of Mishmi Himalaya showing probable movement of the Mishmi Block as shown by arrows

Westward or north-westward movement of the Mishmi Block along Mishmi thrust with anticlockwise rotation; truncation and deflection of the Indo Myanmar Mobile belt against Mishmi thrust in clockwise rotation and northward dextral movement of the E-W trending Western Arunachal Himalayan belt along Bame fault are some of the evidences which may be considered in configuring the tectonic set up of the Mishmi block which acts like a tectonic linkage or roof over the two pillars like IMMB to the SE and WAHB to the west.

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