CHAPTER III
STRUCTURE AND TECTONICS

3.1 Introduction

The Great Himalaya (The ‘Nagadhiraj’ of Kalidasa) is a unique classical example of continental-continental collisional tectonism where leading continental margin of the Indian plate has collided with the Eurasian plate during Himalayan orogeny since 60-50 Ma and is best documented as a youngest and loftiest mountain belt. But such collisional tectonic configurations are least understood in Eastern Arunachal Himalayan belt in comparison to Western Himalayan belt. 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). It has been stated that the Himalayan Metamorphic Belt (HMB) has evolved within a major 15-20 km thick NE dipping ductile shear zone as a cause and effect of intracontinental crustal shortening of Indian plate (Brunal, 1986; Mettauer, 1986; Jain and Anand, 1988) and MCT has brought such piles of HMB by means of tectonic transport above the Lesser Himalayan Belt (LHB).

The most geodynamically active and seismically sensitive orogenic belt of the world is the 2500 km long Himalayan Mountain Belt and it sets as one of the classic example of dynamic Earth. Himalaya forms a curvilinear disposition of arcuate nature showing convexity towards south and extends from Pamir in the west to Mishmi hills to the east. India, Nepal, Bhutan and largely Tibet witness the beauty of the Great Himalaya with the world’s highest peak “Mount Everest” (8847.35 m
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).

Classical MFT is observed between Holocene and Siwalik terrain or Outer Himalaya; MBT between Outer Himalaya and Lesser Himalaya; MCT between Lesser Himalaya and Greater Himalaya; STDS is placed between Greater Himalayan sequence and Tethyan Himalayan sequences at a higher structural height. The northern part of the HHS coincides with a major extensive shear zone as suggested by Burg et al. (1984). This shear zone is the South Tibetan Detachment faults of Burchfield et al. (1992) which has brought the HHS into contact with the unmetamorphosed Tethyan sedimentary sequence of the Tibetan plateau (Visona and Lomberdo, 2002). STDS is also conventionally considered as low angle normal fault or Trans Himadri Thrust (THT) and is roughly parallel to MCT. In different sectors of Himalaya, MCT is interpreted differently but it is a fact that MCT is a metamorphic discontinuity, separating Central Crystalline Metamorphic Belt from low to medium grade metamorphites of the Lesser Himalayan sequences (Yin, 2006; Kumar, 1997; Bhattacharjee and Nandy, 2008). However, HHS is considered as the oldest lithotectonic unit forming the basement complex with Ortho and Paragneisses.

Shyok Suture Zone (SSZ) and its synonymous Indo Tsangpo Suture Zone (ITSZ) are the two literary great Indo-Asian walls, which separate the Asian plate
towards the north and Indian plate towards the south. This zone can be designated as
the natural park of ophiolites. ITSZ of the eastern Himalaya is also known as Main
Mantle Thrust (MMT). Ophiolites are identified all along the ITSZ and probably
limit the northern margin of the Indian plate under subduction configuration.

But the geodynamic signatures and tectonic settings of the highly tectonised
and relatively narrow zone of ophiolitic melange hint rethinking in Arunachal
Himalaya. ITSZ and its extension further towards east in Mishmi block of Arunachal
Himalaya and further SE in IMMB is another aspect to be looked into. Thrust bound
architecture of the Eastern syntaxial bend is discussed by Sarma et al. (2009) and
this aspect is also discussed in the present communication. Unlike Western
Arunachal Himalaya, the concept of Eastern Arunachal Himalaya, MFT, MBT,
MCT and THT is relooked into and equated with the conventional thrusts like
Mishmi thrust, Lohit thrust. In addition, there are a number of thrusts noted by
different workers such as Roing/ Tezu thrust, Lalpani thrust, Tidding thrust, Walong
thrust etc. To remove confusion and for larger interest of Himalayan Orogenic
signatures, a brief discussion is presented here on Mishmi block of the eastern
Arunachal Himalaya. A brief preview of lithotectonic units from south to north
along Roing-Mayudia-Hunli-Anini of Lower and Upper Dibang Valley districts is
referred to here for easy references such as Proterozoic Roing Gneiss, low to
medium grade metamorphites of Dibang Group, Mayudia mafic and ultramafic
complex and Lohit Granitoid Complex.

The Proterozoic Roing gneiss is a structurally thrusted unit over Pleistocene
river terraces bounded to the south by Mishmi thrust (MT). This lithotectonic unit
comprises of 3 distinct lithocomponents such as augen gneiss, amphibolites and
quartzite. The upper boundary of the gneissic unit is the lowermost boundary of the
mafic-ultramafics of Mayudia complex and they are partly associated with metasedimentary units of Dibang Group. The lower boundary of the gneisses is traceable at about 8 km from Roing and structurally overlies the Pleistocene river terraces. Based on lithological characters, the Dibang Group can be separated into lower Ithun Formation and upper Hunli Formation. Ithun Formation is mainly constituted by assemblages of metabasics (amphibolites) and quartzites and they are intercalated with each other. The Hunli Formation is dominantly represented by a thick assemblage of metapelite and limestone. Different varities of metapelites are chlorite-mica schist, quartz-sericite schist, phyllite, carbonaceous phyllite, garnetiferous graphite schist etc. Some thick limestone beds are exposed within the Hunli Formation.

The Mayudia mafic-ultramafic complex is exposed in a synclinal structure along the Mayudia hill ranges. It is an assemblage of ultramafic (peridotite/serpentinite/pyroxinite) and metabasics (metagabbro/metabasalt). The metabasics contain thin intercalation of chert, hornblendite dyke and leucogranite veins. Hornblendite dyke cuts the mafic and ultramafics of the Mayudia Complex. Some isolated bodies of ultramafics are also common within the metasediments of the Dibang Group.

A very fine grained metavolcanic unit is exposed in between the Dibang Group of rocks and Lohit Granitoid Complex, which is a lateral extension of Turing Metavolcanics (TMV) of Siang valley. Amygdules are developed within this metavolcanic unit aligned in a preferred direction.

A NW-SE trending Lohit granitoid Complex (LGC) is exposed in the nortern part of the Dibang valley from Angolin to Anini. This complex is intruded and marks the boundary with metasediment of Hunli Formation near Endolin. The major
rock types are granitoid, granodiorite gneiss, diorite gneiss. Hornblendite dykes are observed near the contact zone along with metavolcanics. Within LGC, crystalline limestone, metapelites and occasionally quartzites are found to occur either as huge xenolith or thrusted sheet (?). As stated earlier that the entire geotransect from Roing to Anini is divided into 5 sectors for lithological and structural mapping.

3.2 Notations of structural fabrics

The symbols used in the text are listed below for convenience of references.

Shear angle ------- $\psi$
Folding angle ------- $\phi$
Direction of maximum extension------- $\sigma_1$
Direction of intermediate extension------- $\sigma_2$
Direction of minimum extension------- $\sigma_3$
Fold amplitude------- $A$
Distance between the two inflection points of a fold along the base------- $M (=1/2\lambda)$
Aspect ratio------- $P$
Bluntness of folding------- $b$
Wavelength------- $\lambda$
Intradose curvature------- $i$
Extradose curvature------- $e$
Arc length------- $a$

3.3 Abstract of structure elements

Structural imprints in the rocks of Dibang Valley sector of Arunachal Himalaya are not homogeneously distributed and penetrative irrespective of rocks all throughout the study area rather they are rock and probably time selective. An attempt has been made to discuss the different deformational episodes in the form of
planar, linear, fold and fault structures so as to evaluate the structural architecture of Mishmi Block along Lower and Upper Dibang valley districts of Arunachal Himalaya. The rocks in this geotransect are affected by four phases of deformation. Deformation partitioning in the lithoassociation is very complex and all the rocks are not affected by four deformational episodes. Moreover, the general opinion about Himalaya irrespective of Mishmi Himalayan Block is that they are polydeformed and polymetamorphosed during Himalayan orogeny leaving imprints of Pre Himalayan fabrics sporadically. The polydeformational history of the Proterozoic gneisses and associated metasedimentovolcanics of the Dibang Group followed by Lohit Granitoid Complex will be discussed here under Pre-Himalayan, Syn-Himalayan and Post-Himalayan stages. While delineating the structural fabrics of the rocks, field based evidences are given more priority irrespective of pre, syn and post-Himalayan orogenic involvements.

3.4 Deformational episodes

The rocks of the Dibang Valley witnessed a complex history of multiple deformational events accompanied by different generations of shear zones. The relative chronological sequences are established and utilized to decipher the structural evolution of the metamorphic belts of the Mishmi Block. The complex lithological and structural map patterns thus portray the signature of polydeformed terrain (Figs. 2.1, 3.1). Whether this polydeformed and polymetamorphic belt is considered as a continuation of the Himalayan Metamorphic Belt, in specific, western Arunachal Himalaya is an open question. 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) Himalayan deformation (Jain et al., 2002). Therefore, the deformational episodes are to be classified and viewed under atleast two heads namely Pre-Himalayan deformation and Syn-Himalayan deformation as stated by many workers (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 (D₁ to D₄), out of which D₁ appears to be Pre-Himalayan and D₂ to D₄ during Himalayan orogeny. On the other hand, Sharma (2005) categorically mentioned that the conventional Lesser Himalayan Crystalline and Higher Himalayan Crystallines were initially the Precambrian crystalline rocks of the Indian plate but modified during Himalayan orogeny. Hence, polymetamorphic and polydeformed aspects of the basement rocks of the Himalaya require rethinking.

Himalaya is one of the geodynamically restless, seismically sensitive and tectonically very unstable orogenic belts of the world and acts as a natural laboratory wherein Precambrian to comparatively young deformational fabrics are registered. The rocks of the study area are mostly schistose and gneissose, therefore, the availability of pervasive planar, linear and fold fabrics and their interferences are considered as diagnostic tools to decipher the different deformational phases. A few lithologies where pervasive planar fabrics are not observed, there, the lithological layering (designated here as S₀) is best considered as a reference surface for structural interpretations.

For better understanding and easy references, the entire geotransect has been divided into three lithotectonic units/domains (a) southernmost domain including
low grade phyllite, quartzite, phyllonite and augen gneiss followed by south central Mayudia synclinal zone, (b) Central domain includes Ithun anticline and metasedimentovolcanics and (c) the northernmost domain covers Lohit granitoid complex. All the three sectors are across the litholayering and generalized strike direction. A comprehensive structural map is prepared and presented here in fig. 3.1 and three notable profile sections are prepared (Figs. 3.2, 3.3 & 3.4).

3.4.1 Non diastrophic structures

Colour and compositional bands, cross stratification, ripple marks are the common non-diastrophic structures observed in the metasedimentary rocks of the Dibang Valley. Highly deformed stratified sequences of mafic and ultramafic rocks of the valley are probably the products of transposition of initial layering due to layer parallel shear couple. The initial configuration of primary bedding is either probably lost or reconstructed due to deformation cum metamorphism in subsequent geologic time.

Graded bedding, ripple marks, cross stratifications and fold mullions are observed in the quartzites of Dibang Group (Fig. 2.36). In limestone stalactites and stalacmites are observed at 87 km (near Hunli).

Some of the mafic dykes are observed and they cut across the NW-SE trending mafic litholayering at high angle in NNE-SSW direction. Such mantle derived mafic bodies are found near Mayudia Pass and north of Lohit Thrust near Angolin. Pillow structure (Fig. 2.11) is one of the diagnostic features of igneous parentage hosted in ultramafic (near Mayudia pass and between Ardzu and Rayalli).

Amygdular basalt is another conspicuous primary feature observed at the contact zone between Lohit Thrust and Dibang Group and the rock seems to be lateral extension of Tuting metavolcanics of north western sector in Siang
geotransect, (after Jain et al., 2002). The amygdules are highly strained and the long direction of amygdules coincides with the X-direction of the strain ellipse (NW-SE). Amygdules are filled up mainly by quartz and calcite.

**Fig. 3.1** Structural map of Dibang Valley, Arunachal Himalaya

### 3.4.2 Structures in southernmost domain (=Lesser Himalayan Sedimentary sequence (LHSS) and Lesser Himalayan Crystalline (LHC))

The southernmost domain is represented by an intercalation of relatively thinly bedded quartzites, phyllites, mylonites and chlorite-actinolite schist and can be equated with Lesser Himalayan Sedimentary Sequences (not a mapable unit, hence not shown in the concerned map). Minor structures within augen gneiss
signatures the presence of earlier planar fabrics where all the later deformational imprints are registered. During intensive mylotinization, the earlier fabrics are transposed intensively and left out as relict, intrafolial, rootless fold (F₁) within the most penetrative ductile shear foliation (CS₂) (Fig. 3.5). Asymmetrically folded augens in mylonitized gneiss show both σ and δ-types, with pressure shadows, S-C shear fabrics and occasional development of mica fishes in M-domains are some of the interesting features observed in augen gneiss (Figs. 2.3 & 2.16). Basic lenses, boudins, pinch and swell structures, stretching lineation quartz ribbon are some of the diagnostic characters which indicate non coaxial deformation (Fig. 2.26). Plunge and direction of stretching lineation along with direction of tectonic transport changes gradually from lower structural level to the higher structural level and such changes are well defined in LHSS and LHC. The mafic lenses are also folded asymmetrically showing left lateral vergence. Some lenses are affected by S-C foliation roughly parallel to the mylonitic foliation and they can be referred to as CS₂ which is axial planar to F₂. The development of CS₂ foliation is considered as reference surface where subsequent deformational history is imprinted and hence plays a vital role in deciphering the Himalayan orogenic episodes.

The mafic and ultramafics of Mayudia Pass can not be tectonically separated with a marked thrust plane but the lithoassociation registered a classified evidence of igneous parentage showing pillow structure, sphinifex texture, bouldery appearance and massive fabrics excepting evidence of shearing effects giving rise S-C foliation along lithofacies of the different layers (Figs. 2.9, 2.19 & 2.22). Marginal serpentinisation makes the rock slippery and polished showing evidence of shearing both sinistrally and dextrally. Minor fold structures are seen and their attitudes coincide with the fold (F₂) of second generation. F₂ mostly maintain sinistral
vergence with low and moderate plunge (top to the south vergence). From Mishmi Thrust to the Mayudia Pass the litholayers show a generalised NE dip, strike being NW-SE and mark the southern limb of the Mayudia syncline (Fig. 3.1)

As noted above, the area witnessed a number of tectonic units from south to north along Dibang Valley namely, (a) Proterozoic gneisses and schists (b) Mayudia mafic and ultramafic rocks (c) Dibang Group of metasedimentary and metavolcanic units and (d) Lohit granitoid complex. The classic evidence of Tethyan sedimentary sequence is not exposed in this valley. Initially, the presence of different structural elements and their mutual relationships/behaviour are described separately for each tectonic unit and finally, a broad correlation between the different tectonic units and their continuation/discontinuation further to the west will be attempted in the present study.
3.4.3 Structures in central domain

The central domain is largely occupied by Ithun anticline with the core occupied by Proterozoic augen gneiss, amphibolites and quartzitic rock sequences. The aerial orientation of the large scale anticlinal structure is roughly NW-SE with a slight deviation to E-W direction. In the Ithun River, the core part is exposed nicely. The northern limb of the anticlinal structure is observed all along the northern bank of the Ithun River to the confluence zone of Dibang River. First generation fold ($F_1$) is marked mostly by quartzite and they are superimposed by $F_2$ and $F_3$. $F_1$ and $F_2$ maintain coaxiality and is associated with $S_2$ (CS$_2$ foliation) along axial planar
orientation of $F_2$ in the generalised NW-SE strike, dip direction is NE with moderate to relatively high angle.

Lohit thrust is the classified ductile shear zone located in between Endolin and Angolin. The metasedimentovolcanics display beautiful fold structure resulting dome and basin (type I interference pattern of Ramsay, 1967) on small scale. In spite of repeated search, no major structure other than Ithun anticline is tracable between Ardzu and Angolin and all the lithounits are dipping due NE. Relatively small scale fold fabrics are showing top to the south vergence geometry. Large scale overturned folds if any could not be ascertained due to thick forestation, inaccessibility and steep gorges of the roughly N-S trending Dibang River.

3.4.4 **Structures in northernmost domain**

This domain is exclusively marked as granite – granodiorite – diorite complex conventionally termed as Lohit Granitoid Complex (LGC) or Mishrni Granitoids. A huge patch of garnetiferous metapelitic rocks is observed within the granitoid either as restites or enclaves. It is hardly possible to establish such patches as tectonic slices. LGC marks the youngest lithounit of the Cenozoic orogeny and suffer from deformation cum partial metamorphic transformation. They imprint two late phases of deformation both being in the ductile environment ($F_1 & F_2 = F_3 & F_4$). Correlation of these two phases with the deformational history of the metavolcanosediments of Dibang Group is attempted.

3.5 **Thrust systems of the Mishmi Block**

Three prominent river valleys - namely Lohit valley, Dibang valley and Siang valley in the Mishmi Hill complex portray the non-uniform thrust bound settings of lithotectonostratigraphy. There are two schools of opinion: one advocates that the Mishmi block is a continuation of Himalaya and hence, MFT, MBT and
MCT are shown in the geological map of Mishmi Sector. Another school suggested the presence of Mishmi thrust, Tidding thrust and Lohit thrust. A brief discussion is given here taking into consideration of both the arguments. In Lohit and Dibang valleys Lower Miocene to Pleistocene Siwalik sequences is either missing or tectonically pinching out towards east, thus acted as a blind sequence overlain by older sequences (Sarma et al., 2009a). Siwalik sequence is exposed in the Siang valley but they do not extend beyond Mebo (Mishra, 2009 and a discussion by Srinivasan, 2009). MFT is present in all the three valleys, are well registered. MFT in Siang sector is marked as floor thrust of Siang antiform and named as North Pasighat Thrust by Acharyya and Saha (2008). The position of MBT is confusing in Eastern Arunachal Himalayan Block (EAHB). Conventionally MBT in both the Dibang and Lohit sectors of Mishmi block is designated as Mishmi Thrust (= Sewak thrust of Mishra, 2009). MT or LHSS is marked at Damwe (13 km from Tezu towards Tohangum) and the same is traceable further towards SE at or near Kamlanagar in the Lohit Valley. In the Dibang Valley MBT is traceable at 8 km north of Roing (28°11'32" N: 95°48'10"E). The LHC lithounit is structurally overlain by Mayudia mafic and ultramafics in the Dibang Valley and represents a intrusive contact. Higher Himalayan Sequence (HHS) is structurally lying over Mayudia mafic and ultramafics and therefore, MCT, if to be placed; it is to be identified in and around 65 km Buddhist camp in Dibang valley. In Dibang valley, Lohit thrust is placed in between Endolin and Angolin (28°30'55"N: 95°57'20"E) and separates diorite-granodiorite gneiss from metasedimentovolcanics of the Higher Himalayan Crystalline (Nandy, 2001). Lohit thrust, as it is coined by earlier worker, is marked between Nara and Paya in Lohit valley and they separate diorite-granodiorite gneiss of the Lohit Granitoid Complex (LGC) to the north and Tidding
ophiolite suite to the south. Earlier worker tried to establish Main Central Thrust near Lalpani area of Lohit valley which separates LHC from HHC. This thrust is designated as Lalpani Thrust (LT) by Gururajan and Choudhury, (2003, 2007); Choudhury et al., 2009; Mishra (2009). Tidding Thrust is another notable discontinuity suggested by earlier workers and it separates the ophiolite suite from HHC near Tidding in Lohit valley. Gururajan and Choudhury, (2003, 2007) and Choudhury et al., (2009) also suggested another thrust near Walong of Lohit valley and named as Walong Thrust (WT) separating less deformed granitoids (hornblende granite) from highly deformed granite granodiorite gneiss and the same is established in the Dibang valley. Thus, a series of thrust from south to north of the Lohit valley whether simply continuing further northwest and exposed in the Dibang valley is a point of further discussion, although recently Mishra (2009) has done it while mapping the two valleys. Nandy (2001) has suggested that the Mishmi block parallels the trend of Mekong Salwin fold belt and the Mishmi metamorphic belt can be correlated with the Mogok belt of Myanmar. He has further suggested that the western block of Arunachal Himalaya terminates against the Siang fracture (=Bame fault) and the Tidding serpentinites is not comparable either with the Y-Z ophiolite or with the ophiolite suite of IMMB. However, it is observed that from south to north along Dibang valley, repetition of the thrusts/contacts are observed and such repetition is caused due to large-scale fold structures observed in Lower and Upper Dibang valley districts of Arunachal Pradsesh. Hence, a broad correlation between the two valleys is probably advisable. Neotectonic activity is stated to be more active towards the foot wall side of the MCT which indicate that rate of recent activation is increasing from north to south. At a higher structural level Tethyan Himalayan Sequences (THS) is not observed in the Mishmi block. Whether, the
THS is under thrusting or overlain by Trans Himalayan Batholithic Sequence (THBS) is another aspect for further study. As regards status of the Siang sector, it is to be noted that the thrust profile of the Siang sector and its morphologic implications do not match with the thrust architectural behaviour of the Lohit and Dibang valleys and hence, the Siang sector probably maintains its own identity and status linked with the continuation of the western Arunachal Himalaya (Sarma et al., 2009a).

3.6 Phase wise description of the structural fabrics

3.6.1 First phase of deformation ($D_1$)

The earliest recognizable deformation ($D_1$) is traceable in augen gneiss and its associated quartzites and amphibolites. Original attitude of lithological layering ($S_0$) cannot be ascertained due to repeated deformation in this polydeformed and polymetamorphic area. From the presence of stratified sequences of the different lithocomponents, it is likely that the present metasediment and metavolcanic units may be deposited under horizontal or near horizontal setting. Transposition of initial litho layering ($S_0$) under horizontal or near horizontal lithosetting might have resulted in the form of a new set of axial plane foliation to $F_1$ and they are considered as reference surfaces, where records of subsequent deformational history were preserved. Intensive layer parallel shortening cum shearing may be the cause of such transposition in the Pre-Himalayan orogenic phase registered in the basement rock. But during Himalayan orogeny they are

![Intrafolial, isoclinal $F_1$ fold in augen gneiss. Locality: 8 km from Roing](image)
extensively sheared resulting CS2 planar fabric on regional scale. Minor F1 fold of first deformation are well preserved in augen gneiss at 10 km post from Roing and also in the core of Ithun anticline around Sukla Nagar (Figs 2.17, 3.1).

3.6.1.1 Fold (F1)

In augen gneiss, F1 folds are found in the form of isolated lenses tectonically sheared out showing mostly dextral pattern (Z). They are marked by either quartzite or thin amphibolite layers encased within most ductile highly sheared quartzofeldspathic gneissic host (Fig. 3.6). They are rootless, isoclinal to tight and occasionally recumbent type (Figs. 3.7, 3.8). Such compressed types of folds are named as tectonic fish (Ghosh, 1993). The aspect ratio (P) of F1 fold varies and accordingly more is the tightness high is the aspect ratio. When less is the tightness, aspect ratio becomes low. The folding angle (ϕ) of F1 varies from 160°-180° whereas in metasedimentary and metavolcanic units it varies from 130°-160° (tight to close type).

The original altitude of F1 is difficult to ascertain due to intensive transposition during Himalayan phase and subsequent rotation during later phases. F1 folds are mimicked by quartz vein (Fig. 3.7) or quartz vein along with thinly layered S0 is folded by F1 and their hinge zone is transected by axial plane foliation S1. Such foliation is seen only in the hinge zone where coaxial planar fabrics S1 and CS2 coincide.
The F$_1$ fold is marked by thin quartzite layers in phyllite exhibiting both right lateral and left lateral vergences and the fold noses are well exposed maintaining W and M type with certain amount of disharmony. The intrados curvature is greater than extrados curvature. The F$_1$ fold axis plunges towards NE and/or SE direction at moderate to high angle (<60°). Occasionally F$_1$ folds show top to the NW and/or SW vergence. Layer oblique fractures in F$_1$ fold sometimes indicate convergency pattern reflecting 1C type of Ramsay (1967). Dip isogon study confirms the above explanation. The thickened hinge and thinned limbs of F$_1$ also suggest similar nature (Fig. 2.17).

![Fig. 3.7 Recumbent ‘Z’ pattern of F$_1$ mimicked by quartz vein in augen gneiss. Location: same as figure 3.6](image1)

![Fig. 3.8 Open to tight F$_1$ fold in augen gneiss, S$_1$ is axial planar. Location: 9 km from Roing.](image2)

### 3.6.1.2 Foliation (S$_1$)

The S$_1$ is axial planar to F$_1$ which was probably the most pervasive planar fabric of D$_1$ deformation in the Pre Himalayan tectonic stage and is defined by mica/chlorite in metapelite, amphibole in metabasites, flattened quart in quartzite, mica, quartz and feldspar in augen gneiss. They cut S$_0$ at maximum angle at the hinges and at low angle or marks parallelism with the limbs. Rarely they are observed in the F$_1$ fold hinge zone where S$_1$ and CS$_2$ make angular relationship to each other.
Such foliations are sometimes become diffused in quartzofeldspathic gneisses. They are generally parallel to the lithological layer boundaries but sometimes make low angles on the cm scale because of shearing. Morphological study of foliation indicates the following types a) Diffused foliation b) axial plane foliation and c) anastomosing foliation, the third type is more prominent pervasive and probably belongs to second deformation superposed on $S_1$ during Himalayan orogeny.

Lithological layering ($S_0$) and shear foliation of second deformation ($S_2$) parallels to $S_1$ is considers 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 variation from NE-SW to almost E-W showing dip either towards NE or SW at moderate to high angles. This reversal of attitude of planar fabric is due to the effect of regional fold structures as well as superposition of later deformation.

3.6.1.3 Lineation ($L_1$)

The $L_1$ lineation is defined by minerals, fold axes, intersection lineation ($S_0 \cap S_1$), and striation, slickensides, stretching lineation, pinch and swell structures, fold mullions and boudins (Figs. 2.26, 2.36, 3.9, 3.10). They are observed mostly along Ithun river valley, the core part of the Ithun anticline. Striations as well as
stretching lineation are developed on the foliation planes indicating the direction of slip and make an acute angle with the strike of the foliation. The long orientation of lenticular boudin axes in metasediments on the XY plane coincide with the $L_1 = F_1$ axes) lineation. The overall variation of the direction of plunge is due to interference of later deformational phases.

### 3.6.2 Second phase deformation ($D_2$)

The second phase of deformation is a major tectonic process of crustal shortening which controls the regional configuration of the lithological layering followed by intensive shearing resulting most pervasive shear foliation ($CS_2$) on regional scale. This phase of deformation is marked by the development of $F_2$ folds on varied scale (from centimetre to hundreds of meter) and development of cleavage ($CS_2$) of pervasive nature and associated lineation ($L_2$).

#### 3.6.2.1 Folds ($F_2$)

The reversal of attitude of lithological layering cum pervasive foliation ($S_1$) is due to the affect of second phase of deformation and they result in lithoshortening in the form of anticlines and synclines ($F_2$). The strike of the axial orientation of $F_2$ folds varies from NNW-SSE to N-S direction all through out the area and is coaxial with $F_1$ showing moderate to sub vertical plunge. $F_2$ geometry varies from tight to
upright, overturned to recumbent with characteristic right and left lateral asymmetric vergences (Figs. 3.11, 3.12, 3.17, 3.19, 3.22, 3.23). In some cases F2 minor folds are mistaken as either F1 or F3 because of their similar style and geometry. They can however be distinguished easily from each other by the overprinting relationship. Minor structures showing ‘S’, ‘M’, ‘W’ and ‘Z’ senses are observed on the different limbs and hinges of the major structures (Mayudia syncline and Ithun anticline) (Figs. 3.13, 3.14, 3.15). In most of the cases ‘S’ shaped folds looking west indicate top to the SW sense of movement. Minor faults are observed and they transect F2 folds at a high angle (Fig. 3.16)
3.6.2.2 Foliation (CS₂)

Foliation developed during second phase of deformation is so intensive that they occur on regional extent. The development of CS₂ is not site selective and rock selective as in the case of subsequent deformations, the later is probably controlled by the rheology of the different rock units. It has developed during Himalayan orogeny as a result of collisional and slip tectonism and almost consume the earlier structural fabrics. Axial plane fracture cleavage (CS₂) is occasionally developed in the competent rock and shear foliation swerve round them maintaining coaxiality. They are also marked by reorientation and slip of earlier minerals along the strain zones and are termed as strain slip foliation. CS2 is axial planar to F2 folding (Fig. 3.20). In the schistose rocks such as graphitic mica schist, chlorite actinolite schist, phyllite, crenulation cleavage is characteristically developed (Fig. 3.18, 3.21). In these rocks the recrystalised micas forming CS2 is bent by F3 open asymmetric fold. The gneissic foliation of the augen gneiss swerves around the basic enclaves and the latter registered the earliest foliation (probably S₁) sometimes parallel to the host rock or sometimes makes different angle with the matrix CS₂ foliation. Such enclaves are occasionally folded, faulted and rotated at varied angles. In the
mesoscopic folds, $S_2$ is curviplanar in nature due to interference of later $D_3$ deformation.

3.6.2.3 Lineation ($L_2$)

$L_2$ is mainly represented by crenulation axis, boudin axis, small scale fold axis, intersection lineation ($S_1\wedge CS_2$) and frequent mineral lineation (Fig. 3.16). They are well preserved in schist as well as sheared amphibolite. The attitude of $L_2$ varies largely due to interference of later folds.

3.6.3 Interference between first and second stages of deformation

$F_1$ being the imprint of earliest deformational event of the area is refolded by $F_2$ folds and this is very common although the latter is a product of Syn Himalayan orogeny and the former is the ancestor of basement of Himalayan orogeny. $S_1$ is the axial planar foliation of $F_1$ cuts across $F_1$ fold hinges but is curved by $F_2$ folds.
Tectonically sheared out lenses of quartzite and amphibolite are the best reflector of

![Fig. 3.22 Upright fold in metabasic from Mayudia area, quartz lenses mimic the structure.](image1)

![Fig. 3.23 Intricate folding of second generation in crystalline limestone. Location: near Ravali](image2)

$F_1$ and $F_2$ interference indicating type 3 interference pattern of Ramsay (1967).

### 3.6.4 Mechanism of folding and foliation

As regards mechanism of folding, foliation and their respective interferences, it may be suggested that intensive layer parallel shearing or slip played an important role in the formation of $F_1$ leading to the development of tectonically sheared out, rootless, isolated intrafolial fold with characteristic thicken hinges and thin limbs. They are attendant with penetrative foliation $S_1$ which is axial planar to $F_1$ and follow the path of tectonic transport direction (x-direction of strain ellipsoid).

Two steps may be inferred:

a) The initial development of fold and associated closely spaced axial planar foliation, the former gradually becoming more and more appressed and finally detached as remnant fold, and

b) Further flattening and transposition of lithological layering leads to the formation of recrystallised mineral, reoriented and restructured under most ductile environment with numerous tectonic fishes indicating the stages of metamorphic history and growth of different recrystallised mineral phases.
As they witnessed multiphase deformation events during Himalayan orogeny, therefore, the initial configuration of the planar fabrics as well as fold fabric is difficult to ascertain.

If we consider that the basement of the Himalaya in Indian context is the Peninsular Precambrian, then their protolithic behaviour of the deformational fabric although restricted during Syn-Himalayan orogeny bears the testimony of Precambrian signature. Identical mechanism may be inferred in the case of second phase deformation but the case history of second phase deformation is extensively populated during Himalayan orogeny irrespective of rock units and layer parallel shear couple played a vital role in the formation of CS2 foliation under NNE-SSW compressional tectonism.

3.6.5 Third phase deformation (D₃)

3.6.5.1 Fold (F₃)

Folds of this phase developed on all scales like microscopic, mesoscopic and megascopic scales. The size varies from centimetre to hundreds of meter through meter. Wavelength (λ) varies in case of crenulations from 2.5 cm to 8 cm and amplitude (A) varies from 2 to 5 cm in average. The trend and plunge of F₃ vary from N30°E to N50°E at low to moderate angle 20°-50°. They are asymmetric with
top-to-the-west and bottom-to-the-east shear sense (Fig. 24). Rarely axial attitudes

change. Upright behaviour with high angle (near vertical) axial plane and near horizontal plunge (±10°) due NE to NNE is observed in most of the metasedimentary and metavolcanic units of the Dibang valley (Figs 3.25, 3.26). In augen gneiss dextral sense of shear is marked by thin quartzite layers (Fig. 3.27). The interlimb angle and wavelength/amplitude ratio are highly variable and such variation depends upon the competency of the rock. The nature of F₃ inner and outer curvature varies from sub rounded to angular through rounded. 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 and enechelon pattern with interference of F₂ and F₃ is manifested (Figs. 3.28, 3.30). A few F₃ fold profile sections are prepared and analysed by dip isogon method and plots are made both manually and in computer using the software “Geometry of folded layers” formulated by P.P.Rodday. The input measured data sets when viewed, most of the plots are fallen in the 1C and 3 type which is a clear indicative of modified similar and modified parallel type. The 1C, 2 and 3 types of folds of Ramsay can be justified in the light of Hobbs et al. (1976) explanation to the viscosity ratio, the amount of shortening and wavelength thickness ratio.
F3 folds are mostly non cylindrical. Occasionally the shorter limbs are thicker than the longer limb and such type of orthogonal variation is a clear indicative of monoclinic strain mechanism (Amenta, 1974). Invariably, the F3 fold axes die out in the direction of plunge. Such type of enechelon geometry indicates conical habit of folds (Dash, 1969).

In some cases F3 and F4 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 D3 deformational episode under simple shear mechanism in the crustal shortening process. Mukhopadhyay et al. (1997 and 2010) also advocated such type of views from Indian Peninsula.

![Fig. 3.28 Down dip plunge of enechelon fold in garnetiferous phyllite](image1)

![Fig. 3.29 Strain slip cleavage (S3) in quartzo-feldspathic gneiss](image2)

3.6.5.2 Foliation (S3)

Strain slip cleavage/ crenulation cleavage/ crenulation foliation is a non pervasive planar structure developed occasionally along site selective and space selective sites and mostly, when developed, they follow the short western limbs of small scale folds or along strain zone sub parallel to the axial plane of F3. Such S3 either destroy S1 fabric or reorientation of early formed micas along such planes.
Crenulation cleavage is also developed in sheared amphibolite. Such cleavage varies from zonal to discrete type (Gray, 1979). Crenulation cleavage and wide spaced fracture cleavage have also been developed which is axial planar to $F_2$ folds. The strain slip cleavages are more conspicuous in quartzofeldspathic gneiss (Fig. 3.29). Such mechanical rotation partly affected the mafic minerals like hornblende, actinolite and lie parallel to the axial planar orientation of $F_3$ constituting $L_3$.

3.6.5.3 Lineation ($L_3$)

Lineation associated with third phase includes minor fold axes, crenulations, intersection of $S_1$ and $S_2$, mineral lineation and rarely rod lineation in case of metapelites. $F_3$ crenulation is of common type. The attitude of $L_3$ constantly corresponds to the $F_3$ fold axis.

3.6.6 Interference between $F_3$ and earlier folds

Interference between $F_2$ and $F_3$ is common throughout the area compared to $F_1$ and $F_2$ interference. In another context interference between $F_1$ and $F_2$ is noted from only the competent rocks whereas $F_2$ and $F_3$ is common manifestation in the incompetent rock. Sense of asymmetry is also noted from the different limbs of the major folds, leading to the development of $S$ and $Z$ geometry. The interference between $F_2$ and $F_3$ is well demonstrated even in the microstructural level where metapelites are showing close to tight $F_2$ folds mostly by micas and limbs are
effected by open folding partly followed by growth of large plates of micas at high angle to $S_1$ lying parallel to sub-parallel to the axial plane of $F_3$ folding.

3.6.7 Mechanism of folding

Thick hinge and thin limbs and almost constant orthogonal thickness of the layers in competent rock suggest that the folds were formed by flexural slip modified by flattening (Ramsay, 1962a). The presence of already well developed shear foliation $CS_2$ during Himalayan orogeny have produced an easy plane along which the flexural slip took place resulting minor $F_3$ and associated $S_3$ and they are the resultant fabric of flexural slip followed by flattening.

Many authors discuss development of folds in competent and incompetent rocks in case of single and multilayered sequences. The thicken hinges and thin limbs in case of incompetent rocks usually suggests Ramsay’s (1967) class 2 type (similar fold) while the competent layers are showing almost uniform orthogonal thickness suggesting Ramsay’s 1B (concentric type). But when individual folds are measured, it is observed that thickness is rather not constant but varies significantly and may be placed under type 1C (modified concentric type). The dip isogons prepared from some profile sections of $F_3$ folds in a multilayered sequence indicate divergence, convergence and parallelism patterns and therefore exact classification is uncertain whether $F_3$ folds are typically concentric or similar but likely to be modified type both in the field of concentric and similar types. It is probable that they are formed by flexural slip along highly pervasive $CS_2$ shear surfaces modified
by flattening (Ramsay, 1962a), such variation may be possible due to their ductility 
behaviour, viscosity ratio, amount of shortening and wavelength/thickness ratio as 
stated by Hobbs et al. (1976).

3.6.8 Refolding of earlier structures by later phases

Interference between F₁ and F₃ is less common than the interference between 
F₂ and F₃; the former type is more obviously preserved in the competent rocks 
whereas the latter type of interference (F₂ and F₃) is more common in incompetent 
rocks. F₁ is closely appressed and isoclinal in habit with attendant axial plane 
foliation occasionally observed and refolded by F₂ with contemporaneous CS₂ 
maintaining coaxial behaviour and type 3 hook shaped interference of Ramsay 
(1967). F₂ axial depression leads to the interference of F₃ with axial orientation to 
the NE-SW direction. The angular variation between F₂ and F₃ is noted between 90⁰ 
and 70⁰ leading to the formation of dome and basin structure- interference pattern 1 
(Ramsay, 1967) (Fig. 3.31). The clockwise and anticlockwise sense of movement of 
F₁ on the two opposite limbs of the major Mayudia syncline and Ithun anticlinal 
structures are shown in the figure 3.1. Axial surfaces of S₁ and S₂ (=CS₂) are sub 
horizontal to moderately dipping due NE while CS₂ and S₃ intersects at high angle 
and the latter plane dips towards NW at moderate angle.

3.6.9 Pattern of major structures

Lithological layering (S₀) and attendant foliation S₁ to F₁ folds when 
computed on the mesoscopic scales it is observed that they are subsequently 
controlled by D₂ deformation resuting major F₂ folds like Mayudia syncline and 
Ithun anticline (Fig. 3.1). In a later stage, the regional F₂ fold pattern have been 
deformed by F₃ during Himalyan orogeny and hence, the present regional structural 
architecture is controlled and modified in totality by second and third phases of
deformation. 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.

3.6.9.1 Mayudia synclinal structure.

This large-scale synclinal structure measures about 30 km accross the roughly NNE-SSW direction. On the southern or southwestern flank of the Mayudia syncline all schistose rocks and their associated foliation have north to northeasterly dip, the amount varying from gentle to moderately steep (Figs. 3.1, 3.2). The northern flank is short and steep; dip varies from 40$^\circ$-75$^\circ$ 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 (Figs. 3.1, 3.3). It is interesting to note that the core part of the Ithun anticline is occupied by augen gneiss, and is exposed all along the Ithun River valley. Augen gneiss first met with at 8 km before Mayudia Pass. The litho profile section is shown in Figure 3.2 and plots of the poles of planar and linear structures are shown in figure. 3.32. For statistical analysis the entire fold area is studied 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 syncline, plots of the poles of CS$_2$ foliation cum litholayering (S$_1$=S$_0$) in the stereonet when contoured clearly indicate a spreading symmetric pattern with $\beta_{CS2}$ axis at 39$^\circ$ towards 019$^\circ$ (NE). Similarly, planar data from northeastern limb when plotted the contour pattern shows elongation with a prominent $\beta_{CS2}$ axis at 60$^\circ$
towards 198° (Figs. 3.2, 3.32). Minor structures associated with the large-scale structures are observed as small crenulations and their statistical mean plots in stereonet coincides with the β-axis of the plots of the planar fabric (fig. 3.32). Planar fabrics of third phase of deformation and their associated fold/lineation fabrics are also plotted in the stereonet and their concentration is seen in mostly NE and SE quadrants (Fig. 3.32).

The traces of the axial surface are curvilinear varying from ESE to SE. The hinge zone passes through Mayudia pass and altitudes of the litholayering also changes from moderate to low angle dip with basic intrusive maintaining discordency with the country rock. The fold profile indicates that the D₂ deformation under NE-SW compressive stress was intense enough and top to the south vergence geometry is registered in this area. It is to be noted further that sometimes the sense
of vergence of $F_1$ fold is not decipherable, though at some places both anticlockwise and clockwise sense of rotation are observed.

### 3.6.9.2 Ithun anticlinal structure

This structure occupies the Ithun river section running roughly in the NW-SE direction, flow direction of the river being towards NW. The closure of the anticlinal structure is observed towards east of Ithun bridge. The core of the anticline is occupied by Proterozoic augen gneiss as stated earlier. In 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 3.32. The southern limb of the Ithun anticline is the northern limb of Mayudia syncline (cf. 63-64). Profile section of the folding of this sector is shown in figure 3.3. Fold behaviour on different scale is an indicative of the gradual increase of intensity of crustal shortening towards south and as such the fold closure is slightly tight type in Mayudia syncline. Vergence of asymmetry is recorded from all sectors and shown in figure 3.1. The anticline is an asymmetric plunging fold with curvilinear fold axis varying in direction from NNW--SSE to NW--SE. Such variation is due to superposition of $F_3$ folding and the trendline 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 nowhere observed in the present study area. One observation can be cited here from geomorphological pattern of the Mishmi Block. It is seen that the east of the present study area belongs to Lohit and Anjow district (eastern part of the Mishmi Block). 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. While in the Lohit sector, the NW-SE trending Tidding River is flowing from NW to SE and merged
into Lohit River. Both Tidding and Ithun rivers are originated from a very high structural level. Therefore, it is obvious that the highlands wherefrom these two rivers are flowing in two opposite direction is the site situated in between Dibang and Lohit valley and might represent on the large scale a domal structure (but the area is inaccessible, thickly forested and snow covered, therefore it is beyond one's reach as on today).

Vergence indicates a simple shear regime with top-to-SW sense of movement. In sectional view looking towards NE, the folds are characteristically S-pattern (Z-pattern looking due SW).

3.6.10 Fourth phase deformation (D₄)

Fourth phase of deformation is marked by kinking, faults, joints and fractures on different scale 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 D₄ is largely a post kinematic phase to the major thrust system. In case of Arunachal Himalaya, Kumar (2001) claims that F₄ is of warp type and related to eastern syntaxial bend. Eastern syntaxial bend and Siang antiform might have developed during D₄ deformation as stated by GSI (2010).

3.7 Kinematic interpretations

Intrusive nature of the augen gneiss is advocated by the presence of basic xenolith and quartzites. 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 CS₂ are parallel to each other and hence it may be
suggested that the emplacement of the augen gneiss is pre-tectonic to D2 deformation and related to syn D1 episode. Stretching lineation is parallel to sub-parallel to the axial orientation of the regional F2 folds i.e. mostly SE with sub-horizontal to low plunge.

The development of major structures is probably 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 phases i.e. pre-tectonic, syntectonic and post-tectonic to Himalayan orogeny. Basic and acidic intrusive were initiated during and after D2 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 sub-horizontal attitudes of mylonitic foliation or S-C fabric with south easterly dipping (~10° to 30°) 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.
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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 ($\sim 10^\circ$ to $30^\circ$) 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.