CHAPTER 3

DEFORMATIONAL HISTORY

3.1 INTRODUCTION

Himalaya is an active mountain belt and considered as storehouse of structural archive of Earth history. The youngest, loftiest and arguably most spectacular of all continent-continent collisional belt on Earth, is the Himalayan orogeny occurring in the east-west direction and created by Indo – Asian collision over the past 70 to 50 Ma (Yin and Harrison, 2000). The Great Himalayan orogenic belt creates an icon of characteristic thrust bound duplex morphology and a stack of important north dipping tectonic slices bounded by Main Frontal Thrust (MFT), Main Boundary Thrust (MBT), Main Central Thrust (MCT), South Tibetan Detachment System (STDS) from south to north and many other locally designated subsidiary thrusts (Sarma et al. 2011).

*Most part of this chapter is based on our papers published


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South Tibetan Detachment System (STDS) separates the Tethyan sedimentary zone of south Tibet from Higher Himalayan sequence (HHS) and the latter is tectonically emplaced with a top to the south vergence over Lesser Himalayan zone by a zone of high ductile shear strain. Traditionally, this zone is designated as Main Central Thrust (MCT). Bhattacharjee and Nandy (2008), Goswami et al. (2009), Yin et al. (2010), Srivastava et al. (2011), Bhattacharjee et al. (2013), Saha (2013), Sarma et al. (2014) and Mazumdar et al. (2014), have studied the rocks of Bhalukpong – Tawang – Zimithang sector and have established multiple phases of deformation grouped under early structures, structures related to ductile shearing and late phase structures.

Sarma et al. (2014) have discussed the structure and tectonics, stratigraphy and magnetic susceptibility of Bomdila Gneiss and work out a number of shear sense indicators and mylonitisation of Bomdila Gneiss. Thrust morphology in the hanging wall side of MCT registered top to the south tectonic transport under N-S tectonic regime. The footwall metamorphic belt is designated as Lesser Himalayan Belt (LHB) constituted by Lesser Himalayan Sedimentary Sequences (LHSS) and Lesser Himalayan Crystalline (LHC). The latter is tectonically emplaced over the former with a top to the south shear sense. Similarly MFT separates recent alluvium zone from the Siwalik sequences. All the tectonic slices are considered to be the counterpart of the north facing Himalayan passive continental margin commonly named as Tethyan Himalaya which develop from Middle Proterozoic to Cretaceous time (Colchen et al., 1982; Brookfield, 1993).

Thus, the study area is basically a thrust bound geounits where major thrusts namely Main Frontal Thrust (MFT), Main Boundary Thrust (MBT) and Main Central Thrust (MCT) besides a number of minor thrusts are observed. South Tibetan Detachment System (STDS) separating the Tethyan sedimentary zone of the south Tibet is not observed in the study.
area. Thrust morphology in the study area with a top-to-south vergence geometry is registered and hinterland and foreland concept is dealt with.

In this approach, the structure of the Lesser Himalayan Sequence and Higher Himalayan Sequence of western Arunachal Himalaya are dealt with along with a thrust bound tectonic analyses. Structural maps of the study area are shown in figures 3.1 and 3.2. It has been noted earlier that the Siwalik and Gondwana sequences are excluded from the present discussion. Siwalik sequence is deformed but unmetamorphosed while Gondwana is deformed and also partially metamorphosed (Figs. 3.3; 3.4). The lithounits of western Arunachal Himalaya exhibit structural trend roughly parallel to the general trend of the major thrusts (i.e. NE-SW) with a steep to moderate dip towards NW to N. Both brittle and ductile deformational effects are seen in these lithounits.

It is noteworthy to mention that the 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 classic documents portrayed by the Great Himalayan Orogenic Belt (GHOB). It has further 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 LHB.
Fig. 3.1 Structural map of Bhalukpong – Tawang traverse showing structural elements of different deformations.

Fig. 3.2 Structural map of Tawang – Zimithang traverse showing structural elements of different deformations.
3.2 DEFORMATIONAL PHASES

Structural identities of all the deformational phases irrespective of penetrative and homogenous nature, are observed in the rocks of the Bhalukpong – Tawang – Zimithang sector of western Arunachal Himalaya. Some of the structures are non penetrative and inhomogenously distributed and some are 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 the West Kameng and Tawang districts of Arunachal Pradesh. The rocks in this geotransect are affected by four phases of deformation. Deformation partitioning in the lithologic assemblage is very complex and all the rocks are not affected by four deformational episodes. Moreover, the general opinion about Himalaya irrespective of eastern and western Himalayan Block is that they are polydeformed and polymetamorphosed during Himalayan orogeny leaving imprints of Prehimalayan fabrics sporadically. The polydeformational history of the Proterozoic gneisses and associated metasedimentovolcanics will be discussed here under Prehimalayan, Synhimalayan and Posthimalayan stages. While delineating the structural fabrics of the rocks, field based evidences are given more priority irrespective of Pre, Syn and Posthimalayan orogenic involvements.

The structural architecture of the northward subduction of the Indian plate beneath the Eurasian 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) Prehimalayan deformation and (b) Himalayan deformation (Jain et al., 2002). Therefore, the deformational episodes are to be classified and viewed under at least two heads namely Prehimalayan deformation and Synhimalayan 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 Prehimlalayan, D₂ to D₃ Synhimalayan orogeny and D₄ as Posthimalayan orogeny. On the other hand, Sharma (2005) mentioned that the conventional Lesser Himalayan Crystalline and Higher Himalayan Crystalline 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. Question arises why only one phase of deformation (D₁) of the Indian crust is considered as Prehimalayan fabric and all rest episodes are erased away during Synhimalayan orogeny?

However, the structural analyses are discussed below under two main head namely (a) structural history of Lesser Himalayan Sequence and (b) structural history of Higher Himalayan sequence.

3.2.1 STRUCTURAL HISTORY OF LESSER HIMALAYAN SEQUENCE

Lesser Himalayan Sedimentary Sequence (LHSS) and Lesser Himalayan Crystalline (LHC) are the two major lithological sequences, the former is conventionally designated as metasedimentary and the latter by crystalline complex. All the structural fabrics are discussed under a single head.

As stated above, the Himalayan metamorphic belt bears the identities of deformational fabrics belonging to Prehimalayan episode, Synhimalayan episode and Posthimalayan episode covering Proterozoic to early Pleistocene periods. On the broad sense, the Himalayan Metamorphic Belt has undergone atleast four phases of deformation indexed as D₁ to D₄ and the Himalayan granitoids (1800-2000Ma) contains relict Palaeoproterozoic structures (Jain et
Similar observation is also forwarded by Sarma et al. (2014) and Mazumdar et al. (2014).

The general structural trend of the lithological layering in the Western Arunachal Pradesh is NE-SW showing moderate to steep dips towards NW, parallel to sub parallel to the general trend of the major thrust systems in this region. The lithological units show the effects of both ductile and brittle deformations. In metasedimentary units of the Lesser Himalayan belt are classified as Tenga Formation (= Dedza Formation = Cheillipam Formation = Buxa Formation), Dirang Formation and Lumla Formation while crystalline belt incorporates only Bomdila Gneiss.

Structural history of the Lesser Himalaya Crystalline (Bomdila Gneiss) is discussed under Chapter 5, therefore, to avoid repetition it is referred to only.

It is generally accepted that the Himalayan orogenic belt displays characteristic thrust duplex morphology and accommodate a number of south vergent thrusts. The involvement of basement rocks of the Indian plate in the Himalayan orogen display a great role in the structural evolution and tectonic framework of the orogen by vertically moving up because of buoyancy and pushed southward over the younger rock sequences (Bhattacharya, 2008). The Himalayan metamorphic belt (HMB) along Bhalukpong- Tawang- Zimithang geotransect bears the identities of deformational fabrics belonging to Prehimalayan, Synhimalayan and Posthimalayan episodes from Proterozoic to lower Pleistocene periods.

The study area is a part of the thrust bound systems i.e. the different tectonostratigraphic zones separated by a number of major thrusts namely MFT, MBT and MCT in addition to a few minor thrusts (Figs. 3.1 and 3.2). South Tibetan Detachment System (STDS) separates the Tethyan sedimentary zone of the south Tibet from Higher
Himalayan Sequence (HHS) (not observed in Indian subcontinent) and the latter is thrust over Lesser Himalayan Sequence (LHS) by a zone of high ductile shear strain, traditionally designated as MCT. Thrust morphology in the hanging wall side of MCT registered top to the south tectonic transport under N-S compression. LHS is thrust over Siwalik sequences with a top-to-south vergence geometry and acts as the hinterland of the foreland Siwalik sedimentation.

Deformational history of the Lesser Himalayan Sequences of West Kameng and Tawang districts of Western Arunachal Pradesh has been discussed by a number of authors (Bhusan et al., 1991; Kumar, 1997; Yin et al., 2006; Bhattacharjee and Nandy, 2008; Goswami et al., 2009; Srivastava et al., 2011; Saha, 2013; Sarma et al., 2014; Mazumdar et al., 2014). Bhattacherjee and Nandy (2008) have suggested two phases of deformation in the Lesser Himalayan Sedimentary sequences and one phase of deformation in Lesser Himalaya Crystalline (Bomdila Gneiss). Goswami et al. (2009) also have suggested three phases of deformation (D1 to D3) and two groups of planar structures (S1 and S2). Srivastava et al. (2011) have delineated four phases of folding F1, F2, F3, and F4 where F1 and F2 are coaxial.

The primary structures (ripple marks, current bedding), within the quartzites of the Dirang and Lumla Formations, are poorly preserved due to effects of deformation and metamorphism. Bedding, defined by compositional layering and colour lamination within quartzite probably represents initial layering designated as S0 is seen. The general trend of the lithological layering is the generalised strike orientation due NE-SW with moderate to high dip towards northwest. The original attitude of the sedimentary layering is very difficult to ascertain due to subsequent later deformational impact.

Along Bhalukpong – Tawang – Zimithang geotransect, LHSS bear the testimony of earliest planar fabric (S0=S1) and relict intrafolial, rootless fold of first generation (Figs.
Folds are of similar type showing thickened hinge and thin limbs. The host rock portrays axial planar foliation (CS₂) parallel to S₁ truncating F₁ hinge at high angle and roughly parallels to the limbs (Figs.3.7 and 3.8). The pervasive foliation deflecting lenses or rigid bodies also parallels to axial planar and is considered as product of later D₂ phase – designated here as CS₂ (Fig.3.19). Such relict fabrics of D₁ deformation is treated under Prehimalayan phase and they are the true representation of the Indian Crustal plate as relict fabric. On the other hand, D₂ is Synhimalayan deformation and it was so intense that most of the fabrics of the Prehimalayan deformation in Proterozoic basement rocks were either destroyed, transposed, obliterated and/or restructured during Himalayan orogeny imprinting regionally pervasive ductile shear (C-S) foliation, indexed as CS₂, stretching lineation (L₂), reclined, open asymmetric, sheeth fold (F₂) and contemporaneous axial planar fabric during D₂ deformational episode. These deformational fabrics are all registered in the metasediments of Lesser Himalayan Belt.

Kink band, minor faulting, N-S trending quartz, tourmaline, feldspar veins and brittle fractures define fourth phase of deformation. Emplacement of dolerite and basaltic dykes is hardly correlatable with a definite deformational phase but can be categorically placed under post Himalayan orogenic cycle, free from metamorphism and follow structural locals in the NE-SW, NW-SE and N-S directions. The latter two directions truncate regional orientation of the different lithocomponents of the Himalayan Metamorphic Belt in the context of subducted Indian plate configuration.

Srivastava et al. (2011) have classified all the four deformational events under three successive stages in relation to the development of MCT, eg. D₁ and D₂ as Pre MCT, D₃ as Syn MCT and D₄ as Late MCT. However such correlation is difficult to establish without geochronological evidences.
**Fig. 3.41:** "Z" type right south vergence $F_2$ folds in SeLa gneiss marked by quartz vein. Location 6 km from Dirang towards Tawang. Coin diameter.

**Fig. 3.42:** Line diagram of 3.41.

**Fig. 3.43:** "Z" type right south vergence $F_2$ folds in SeLa gneiss marked by quartz vein. Location 6 km from Dirang towards Tawang.

**Fig. 3.44** Line diagram of 3.43.
**Fig. 3.45** $F_2$ fold is marked by quartz rich band in metapelite. CS$_2$ is axial planar to $F_2$. **Fig. 3.46** Garnet porphyroblast enclosed within metapelite. The shadow zone is occupied by tightly folded micas. The CS$_2$ truncate earlier foliation. Garnet encloses $S_i$ fabric and shear fractures parallel and perpendicular to CS2. **Fig. 3.47** Similar to 3.46 Garnet (pre-TECTONIC to $D_2$) porphyroblast bears straight trails of small inclusions of quartz and magnetite. **Fig. 3.48** Same as above but garnet encloses internal fabric and shear fracture parallel to direction of garnet porphyroblast. $S_i$ fabric both deflects and truncate garnet porphyroblast indicating syn $D_2$ deformation. **Fig. 3.49** Two stages growth of garnet. Both core and rim of the garnet is transected by shear fractures related to later event. **Fig. 3.50** Elongated garnet lie at high angle to CS$_2$. Shear fractures are parallel to CS$_2$. 
**Fig. 3.51:** Faulted quartz layer of extensional tectonics; fault surface trends left top to right bottom observed in SeLa gneiss. Location: 10 km to SeLa pass. Ball pen length 15 cm. **Fig. 3.52** Line diagram of 3.47. **Fig. 3.53:** F2 folds in metabasic rocks of Jaswantgarh area showing south vergence ‘z’ pattern. Fold axis plunges towards east. Length of ball pen: 15 cm **Fig. 3.54** Line diagram of 3.50.
Fig. 3.5: Tight appressed F₁ fold in Dirang Formation of LHSS with thickened hinge and relatively thin limbs. Fold axis plunges NE at moderate angle, axial plane is near horizontal, location: south of Dirang.

Fig. 3.6: F₁ fold of isoclinal nature in Dirang quartzite; axial planar orientation almost E-W. Minor fault plane is observed on the bottom part of the folded layer. Coin diameter: 2.5 cm.

Fig. 3.7: Isoclinal fold marked by quartzite of Dirang Formation. S₁ is axial planar to F₁ but S₁ is transformed further to CS₂ in the host rock. Length of the pen: 15 cm.

Fig. 3.8: Line diagram of 3.7.
Fig. 3.9: Hook shaped interference pattern between $F_1$ and $F_2$ associated with $CS_2$ in Dirang Formation. Location: contact zone of Bomdila gneiss and Dirang Formation. Length of the pen 15 cm. Fig. 3.10: Open, upright $F_3$ fold in Lumla Formation with dextral motion. Location: near Lumla. Fig. 3.11. Alternate layers of quartzite and metapelite of Dirang Formation showing interference between $F_1$ and $F_2$ asymmetric folds, plunging towards NE. photograph facing NE. Fig. 3.12: Highly deformed phyllite of LHSS, south of Nagmandir area showing kinking ($F_3$) with near horizontal axial plane trending N-S. Minor crenulations show low angle plunge due NW.
Fig. 3.13. Dextrally moving vein quartz lens enclosed within CS$_2$ foliation (top to bottom) in metasediments of LHSS. Length of ball pen 15 cm. Fig. 3.14; Interference of two phases of deformation (F$_1$ and F$_3$). The dominant pervasive foliation is CS$_2$ = S$_1$. Fig. 3.15: Highly crenulated thinly bedded, sheared quartzites and metapelites. Quartz/quartzite lenses are tectonically attenuated in the direction of tectonic flow (=CS$_2$). Sinistral sense of shear is marked. Coin diameter: 2.3 cm. Fig. 3.16: Lumla Formation dominantly made up of quartzite and metapelite (garnet zone) show SW vergence, low angle F$_3$ fold axis plunging NW. The generalized dip of the litholayers is NW corresponding to plunge direction of the F$_3$ folds.
Fig. 3.17a: light brown coloured metapelite layer enclosed within highly sheared quartzite from Dirang Formation. Similar type ‘M’ pattern with i>e. Fig. 3.17b: line diagram of Fig. 3.17a. Fig. 3.18: Similar to previous photo (close up view facing north). Colour lamination of quartzite is seen. Fig. 3.19: anastomosing shear foliation in quartzite of the Tenga Formation. Location: 5 km from Nagmandir towards east along river valley. Coin diameter: 2.1 cm
3.2.1.1 Mesoscopic structures

The LHSS (consisting of Tenga, Dirang and Lumla Formations) is composed of phyllites, carb-phyllites, quartz-mica schist, micaceous quartzite, quartzite, limestone, phyllonite and mylonites with metavolcanics like actinolite-chlorite schist and amphibolites. Generalised strike of the Dirang metasedimentaries are NE-SW with an average dip 40°-60° towards NW. The LHSS display structural identities of four different phases of deformation resulting planar, linear and fold fabrics and typical interference patterns are imprinted on them. On the regional scale, pervasive planar fabric is designated as CS₂ (shear foliation), a planar fabric developed during Himalayan orogeny (= S₂ of Goswami et al., 2009). Prehimalayan signatures are still preserved in metasedimentaries and they act as relict F₁ fold associated with axial planar foliation S₁ showing both ‘S’ and ‘Z’ types (Figs. 3.5; 3.6; 3.18). S₁ strikes NE – SW showing generalized NW dip at moderate angle. F₁ is close, appressed, isoclinal type and the contemporaneous foliation transects S₀ at high angle at the hinge zone of F₁ (Figs. 3.5 to 3.8). The effect of minor faulting is observed on one limb of the F₁ fold (Fig. 3.6). Such fabrics are readjusted and restructured during Himalayan orogeny resulting pervasive shear foliation (CS₂) irrespective of lithounits and further affected by successive deformational phases and their interferences (Figs.3.9; 3.10; 3.11). In amphibolite, rarely S₁ is observed in the hinge zone of minor F₂ folds and intersect CS₂ at high angle. Crenulations and folds on minor scale are observed with a generalised axial orientation NW-SE (Fig. 3.14, 3.15). F₂ and F₁ folds maintain coaxiality in some cases. F₂ plunges 40° to 60° towards W or SW. Southeastern limb of F₂ is mostly short and steep while northwestern limb is gentle and long. Overturning character of F₂ is marked in many places showing top to S or SE vergence (Figs. 3.9 to 3.11). The superposition of third phase deformation is documented by metasedimentaries and metavolcanics of LHSS (Figs. 3.10; 3.12; 3.15; 3.27; 3.28). The generalised axial orientation of F₃ fold is NW-SE showing plunge towards NW at moderate ≈
45° angle (Figs. 3.10; 3.16). The behaviour of F3 is moderately closed, open to warp type and the fold pattern and geometry indicates with top-to-SW vergence as against the S – SE vergence of F2. Interference between L2 and L3 is common in the form of minor crenulations in Dirang Formation (Figs. 3.29). Stretching lineation seen in quartzite is correlatable to D3 deformation indicating NW to NNW slip direction. Culmination and depression (F2 and F3) on minor scale is seen (Fig. 3.24). Mild curvature of the axial orientation of F3 trending roughly N – S, minor kink fold in phyllites, small scale faults and fractures observed in different rocks are classified as F4 (Figs. 3.8; 3.13; 3.22; 3.23).

3.2.1.2 Microscopic Structures:

The rocks of the LHSS have undergone repeated deformation cum metamorphic transformation during Himalayan orogeny. Intensive structural readjustments during Himalayan orogenic movement have either erased away most of the Prehimalayan Indian plate related microscopic /mesoscopic structural evidences (see p. 61) except some small scale isoclinal to tight appressed folds and rarely preserved planar fabrics in the hinge zone of F2 folds of coaxial nature with F1 where dominant shear foliation (CS2) maintain cross cut relationship. Such fabrics are rarely preserved in the mafic enclaves within Bomdila Gneiss. Synhimalayan ductile phase results CS2 all throughout the rock units (LHSS and LHC) and is axial planar to F2 showing structural trend roughly NE-SW with moderate plunge either NE or SW direction (Fig. 3.33). In metapelite both M and Q-domains are observed and they are folded by F3 and wrap round garnet porphyroblast showing both σ and δ type of rotation. Garnet bears the identities of straight trails of inclusion, sygmoidal rotation marked by tiny quartz grains, minute opaques (cf. p.78) and also intertectonic stage bearing Sc fabric as Si within garnet (Fig. 3.32). In garnetiferous phyllite of Dirang / Lumla Formation continuous cleavage (CS2) is marked by flattened quartz, parallel alignment of biotite and muscovite and
sometimes elongate skeletal garnet or garnet aggregates. Three generations of micas (m₁ to m₃) are identified: (a) small flakes occurring as inclusion in garnet or feldspar porphyroblasts (m₁), (b) as big flakes of mus₂ and biot₂ defining pervasive foliation (CS₂) which often wrap round different porphyroblast or sometimes truncates (m₂). They define folding of later generation (F₃ and F₄) and (c) as broad and short flakes superposed on CS₂ at different angle mostly along strain zones of F₃ and F₄ folding (m₃). Thus m₁ is interpreted as D₁, m₂ as Syn D₂ and m₃ as syn to post D₃ stages of folding. Actinolitic hornblende also marks similar behaviour. In LHC, the protolithic feldspar phenocrysts suffer tectonic attenuation and form augen defining CS₂ with mostly right lateral sense of rotation. Such asymmetric vergence marked by rotational movement of the strain markers and associated folding is a clear indicative of non – coaxial deformation under simple shear movement picture. CS₂ is highly crenulated showing extension crenulation cleavage, zonal crenulation cleavage and fracture planes (without growth of new minerals) (Figs. 3.34; 3.35). Interference of F₂ and F₃ is well defined in metapelites of the Dirang and Lumla Formation of LHSS (Fig. 3.35).

Intrgranular kinking and microfaulting of extensional habit in feldspar augens are also seen. Shearing and grain granulation leads to anastomosing foliation and mortar texture. Metapelites and metabasites from foreland part of the MCT zone show high degree of shearing and intensive quartz veining from both Dirang and Lumla areas. Similar observations are also observed along the Lumla – Bhutan road.
Fig. 3.20: open asymmetric fold marked by quartzite of Lumla Formation. Location: near Lumla Village. Coin diameter 2.5 cm. 

Fig. 3.21: Open asymmetric F3 fold associated with axial plane fracture cleavage trending NW-SE from Lumla Formation. Minor displacement is seen.

Fig. 3.22: A series of minor faults (top to bottom orientation) is marked by quartz vein in the quartz-sericite schist of Dirang Formation. Coin diameter 2.5 cm. 

Fig. 3.23: a series of minor faults (top to bottom orientation) is marked by quartz vein in the quartz-sericite schist of Dirang Formation. All faults show extension tectonism.
Fig. 3.24: Culmination and depression is observed on the XY plane of the strain ellipse in Tenga Limestone near Nagmandir. Length of the pen: 15 cm. Fig. 3.25: Nagmandir conglomerate separating LHSS from LHC. Fig. 3.26: Shergaon conglomerate with highly stretched pebbles parallel to subparallel to CS2 (E-W direction). Fig. 3.27: Asymmetric F3 folds in LHSS (Dirang Formation), axial plane trends NW-SE (top to bottom) with mild curvilinearity. Coin diameter: 2.3 cm.
Fig. 3.28: Asymmetric $F_3$ folds in LHSS (Dirang Formation), axial plane trends NW-SE (top to bottom) with mild curvilinearity. Fig. 3.29: Dirang phyllite near Shergaon conglomerate. Two sets of lineation are observed. The early set is rolled over the fold axis and later set is parallel to the fold axis ($F_2$) maintaining asymmetry (almost overturned) towards south. Length of the ball pen: 15cm. Fig. 3.30 Conjugate $F_2$ fold. Fig. 3.31: Alternate M and Q domain in metapelite, folded by $F_3$ of open upright type.
Fig. 3.32: Syn D₂ garnet with sygmoidal S₁ fabric of dextral sense. Fig. 3.33: Close to tight F₂ is marked by quartzite and thin metapelite. CS₂ is axial planar. Fig. 3.34: CS₂ is folded by F₃ fold; S₃ is axial planar to F₃. Fig. 3.35: Interference of F₂ and F₃ in alternate metapelite and quartzite
3.2.1.3 Strain Analysis

Strain in rocks can be calculated with the help of strain markers such as ooids, spherulites, radiolarian shells, foraminifera, pebbles of conglomerates, brecciated mass, augens, ribbon quartz, amygdoles etc. In this study, deformed pebbles of conglomerate observable at mesoscopic scale were considered as strain marker to quantify finite strain (Fig. 3.26). It is difficult to ascertain whether initially the pebbles of conglomerate were spherical or elliptical but the present disposition of pebbles act as kinematic indicators. For comparative study and correlation purpose, strained quartz from associated rock components are also considered side by side. They exhibit significant stretching and rotation when they undergo deformation. The conglomerates near Shergaon (hereafter will be referred to as Shergaon Conglomerate) are highly deformed, stretched, fragmented, rarely faulted and rotated as against the Nagmandir Conglomerate which is less deformed (Figs. 3.25; 3.26).
The generalized strike of the conglomeratic horizon is NE-SW and the long axes of the pebbles are generally parallel to the S-C foliation (CS₂) cum interfaces of the underlying lithosetting. In the field, pebbles are measured on the XZ plane as well as YZ plane and their long and short axes are calculated (see inset diagram over fig. 3.38). The average size varies from 0.77 – 12 cm in length (X) and 0.36 – 4 cm in breadth (Z). In one road section, YZ section of the conglomerate horizon is exposed wherefrom photographs and a few measurements are taken. Ramsay (1967) described $R_f/\phi$ technique for measuring strain from any deformed strain markers and subsequently it was modified by Dunnet (1969) and Lisle.
It is not possible to ascertain the original size of the strain markers before deformation even if the shape parameter is known. Hence, some sorts of assumptions are made to proceed for their calculations. Similar is the case of initial orientation of such markers. As manual calculations with some amount of assumptions is relatively time consuming, therefore, computer based software are used in the present analysis. Initially, it was thought of that the strain estimation could be made by Fry method from isotropic anti clustered distributions of strain markers that was deformed homogeneously (Fry, 1979; Hanna and Fry 1979). But often it is observed that the strain markers are affected by heterogeneous deformation and the original pre deformational centres of the markers are difficult to define. Therefore, calculated centroids will underestimate finite strain in Fry plots and as such more is the heterogeneity more is the error. Out of different methods available for strain analysis, only four methods are adopted for the present study namely (1) Flinn plots (Flinn 1962), (2) Ramsay and Wood plot (Ramsay 1967; Ramsay and Wood 1973), (3) $R_t / \phi$ plots (Ramsay 1967; Dunnet 1969; Dunnet and Siddan 1971), (4) Fry method (Fry 1978, 1979; Hanna and Fry 1979). These plots are prepared using the software ‘Sixstrain’ developed by P.P.Roday (2003).

Section wise pebbles are drawn on transparent overlays and field photographs were taken in the field. The conglomerate is so friable that it is hardly possible to cut the sample in required orientation. Even it was not possible to collect oriented samples with
respect to lithological layering or dominant CS$_2$ foliation of Syn Himalayan deformation. However, photomicrographs are made use of in preparing strain diagrams. The lengths of the long (X), intermediate (Y) and short (Z) axes of the deformed pebbles are measured with the help of transparent overlays and enlarged photographs with scale. Axial ratios (R$_f$) of XZ and YZ sections and orientation of major axes with respect to the reference line ($\phi$) is also calculated (n=45). Recently, excel supported spread sheet based approach to R$_f$ /$\phi$ strain analysis was formulated by Chew (2003) which is more easier method in calculating symmetry of R$_f$ /$\phi$ plot and initial orientation of the strain markers.

Flinn diagram prepared from Shergaon Conglomerate reveal that has all the plots lie in the flattening field (oblate type) with characteristic mean value $k = 0.2696$, which is less than 1 indicating simple shear mechanism (Fig. 3.36). It is difficult to differentiate pure shear from simple shear in a multideformed terrain, although there is a customarily accepted fact that when $k>1$, it is L-tectonite, $k<1$, is S-tectonite and $k=1$ is LS-tectonite. As S-tectonite is reportedly deformed along with elongated pebbles and make angular relationship with the reference line (= interface) between conglomerate and associated rock, therefore, it is considered as simple shear. Ramsay and Wood (1973) plot also indicate the flattening field ($k = 0.3684$) (Fig.3.37). From graphical plots of R$_f$ vs. $\phi$ finite strain (R$_s$) values were determined by visual best fit into the standard curves of Dunnet (1969). The plots of the data in R$_f$ /$\phi$ plots indicate that the $\phi$ angle is relatively less in XZ section than that of YZ section. The population of R$_f$ values is not highly scattered but they have a rather narrow $\phi$ values (Figs.3.38; 3.39). It is seen than the vector mean of the pebble long axes on the XZ section is not parallel to the CS$_2$ plane. Fry plots are prepared from photographs as per standard methods show an elliptical vacant area of no concentration around the central part. The
average ratio of long and short axes is 2.47 (Fig. 3.40). The calculated long axis of the ellipse makes 15° with respect to reference line (CS₂) which indicate simple shear.

In the outcrop scale strain appears to be homogeneous but on the regional scale, heterogeneity prevails on the entire Lesser Himalayan Sedimentary Sequence.

### 3.2.2 STRUCTURAL HISTORY OF HIGHER HIMALAYAN SEQUENCE

Both HHS and underlying LHS are structurally deformed by multiple phases irrespective of Pre Himalayan or Syn Himalayan orogenic identity. They are separated by MCT, although the latter is being designated as a zone of intensive ductile shear registering / displaying N or NNW moderate dip and southward upthrust sequence. Variation of lithounits and grade of metamorphism both in the hanging wall/hinterland (HHS) and footwall/foreland (LHS) parts of MCT indicates that the deeper part of the Indian crustal plate is remobilised or readjusted and pushed upward by vertical movement and emplaced over LHS during Indo – Tibetan collision tectonics. An attempt is made in this approach to treat the deformational history of the HHS of the study area separately to peep into whether there is any structural discontinuity between LHS and HHS the way lithounits and grade of metamorphism vary from lower structural level to higher structural level.

In a most general way, HHS can be treated as the basement rocks of Himalayan orogenic domain (Bhattacharyya, 2008). On the regional scale all the piles of rocks from south to north show a generalised N or NNW dip as if it acts like a homoclinal structure. But, if carefully observed, a number of map scale to outcrop scale up and down facing folds (anticlines and synclines) are seen along this geotransect. Although thrust sheets are dipping roughly northward at moderate angle, such stack of thrust bound lithotectonic units are of
imbricate nature with a roughly top to the southward vergence. Such translatory movement is largely due to crustal shortening process during continent–continent Indo – Tibetan collision.

Further, it is also observed that although the major subdivision of Himalaya is HHS, inspite of that the Himalayan structural architectures in HHS are relatively simpler in comparison to LHS. It seems unusual but it is a fact. Bhattachayya (2008) is of the opinion that the ductile strain is increasing towards the zone of MCT. The hanging wall of MCT i.e. HHS is constituted by remobilised crystalline basement of about 30 km thick medium to high grade metamorphic sequence such as augen gneiss, quartzofeldspathic gneiss, granite gneiss, garnet – biotite – sillimanite gneiss, biotite – muscovite gneiss, calc silicate rocks, quartzites, aplites, pegmatites, basic dykes and leucogranite in general in the entire Himalayan belt irrespective of sectors. The deformational imprints of HHS are discussed below in order of mesoscopic, macroscopic and microscopic structrures.

3.2.2.1 Mesoscopic and microscopic structures:

Unlike mesoscopic structures related to LHS, the HHS also display a set of planar, linear and fold structures irrespective of competent and incompetent rock units in the hanging wall of the MCT zone. The main lithounits of HHS is quartzofeldspathic gneiss and migmatite, massive quartzite, garnetiferous amphibolites, garnet – sillimanite bearing metapelites, metabasites, leucogranite, pegmatites and vein rocks.

The general trend of schistosity within the gneisses of SeLa Group is mainly NE-SW with variation to NW-SE showing moderate dips towards NW and/or NE. In the upper structural levels the schistosity is folded to form overturned folds, as observed 10 km north of Baisakhi camp near SeLa Top (Fig. 3.56). Overturned fold of closed nature is also observed within the calc silicate rocks occurring as enclave within the gneisses of
SeLa Group north of PTSo. All the folds are of second generation. Earlier folds are rarely preserved. The lithounits of SeLa Group are thrust over the metasedimentary sequences of the Dirang Formation.

All the four phases of deformations indexed as D₁ to D₄ as in the case of LHS, are observed in different lithotectonic units. We have identified them as Prehimalayan (D₁), Synhimalayan (D₂, D₃) and Posthimalyan (D₄) phases as against basement of D₁ and D₂ as Pre Himalayan and D₃ and D₄ Synhimalayan phases by Srivastava et al., 2012. Our structural setup has similarity with the finding of Goswami et al. (2009) and dissimilarity with Bhattacherjee and Nandy (2008), the latter have established only two phases of deformation in the HHS of the Tawang sector of Western Arunachal Himalaya. The asymmetry of F₂ folds is more intense nearness to the MCT zone of hanging wall near Jashwantgarh area and marked as top to the south vergence geometry (Figs. 3.41 to 3.44; 3.53; 3.54). Minor crenulations in metapelites show variation of fold pattern from asymmetric to overturned and strain slip cleavage along short overturned limb is conspicuous. Most of the lithounits of the HHS show dip at moderate angle due north or northwest direction (Fig. 3.55).
The axial orientation varies from NE-SW to E-W, plunge being either towards NE and / or SW at relatively low to moderate angle. They may bear the identity of folds of large scale structure (discussed in later phases).

The imprints of D3 deformation in the form of folds (F3), is sometimes confusing because of variation of their orientation as well as patterns. Specifically in the migmatites the flowage behaviour is more conspicuous and such flow folds are difficult to identify unless interference over F2 is well defined. In general, F3 is less tight i.e. they appear to be close to open type, plunge being towards NW or NNW at moderate angle (~50° – 65°). Small scale culminations and depressions (domes and basin structures – type I interference pattern) is marked by metapelites on the XY plane where L2 is well defined. Doubly plunging of L2 is seen and is marked by minerals, boudins, pinch and swell structure and enechelon quartz veins. Ptygmatic fold marked by vein quartz with axial orientation in the NW-SE direction is another conspicuous features of the HHS. The initial attitude of the litholayering is totally lost and the present disposition of lithosetting is purely the cause and effect of basement crustal shortening of the Indian plate during Indo–Tibetan plate collision. Development of planar fabric during D3 is rock and site selective. Fracture cleavage along axial plane of F3 is frequently observed in most of the competent rock units. Crenulation cleavage and strain slip cleavage are seen in metapelites and sheared quartzite. Enechelon quartz veins with sigmoidal pattern making NW-SE orientation is superposed on earlier set of enechelon veins of D2 phase and they are treated as indicator of interference pattern between D2 and D3. Slickensides and striations are also seen trending NW direction.

The fourth phase of deformation may be treated as Posthimalayan phase rather may also be designated as ongoing phase of deformation. Faults, fractures and others brittle features are marked as last phase of the active Himalayan tectonics. Minor faults planes are
seen in N-S orientation (Figs. 3.51; 3.52). Sometimes kink bands are also observed parallel to such orientation.

In the HHS, metapelites and amphibolite bear the testimony of probable earliest planar fabric (designated as S1) and is defined by relatively small grains / flakes of actinolite (?) and micas in amphibolites and metapelites respectively and they are truncated by coarse grain hornblende plates, micas, flattened quartz and opaque (CS2) (Figs. 3.45 to 3.50 ). The latter defined as pervasive foliation occasionally deflecting round rigid garnet porphyroblast. The relict S1 fabric is also enclosed within garnet porphyroblast as S1 inclusion trails (internal schistosity) either sygmoidally rotated or straight trails discordant to the external foliation (CS2) (Fig.3.45 ).

Garnet porphyroblasts of the metapelites occasionally registered such S1 fabric (Fig. 3.47). In metapelites garnet bears such S1 fabric marked by minute opaques, tiny quartz grains and lie at oblique to external foliation which wraps round the porphyroblasts probably during simple shear mechanism of D2 deformation. In micaceous sheared quartzite between M-domain and Q-domain relatively small fabric of mica flakes mark tight F2 fold with associated CS2 as axial planar (Fig. 3.31) which might have been transported by intensive shearing during Himalayan orogeny under D2 phase. Banded gneiss, migmatite highly sheared amphibolite and mylonitic quartzite with grain granulation grain boundary, subgrains phenomena, ribbon fabrics and flow fabrics marked by sillimanite needles along with embedded on feldspar and micas are all related features of Synhimalayan D2 deformation.

3.2.2.2 Macroscopic structures

In most of the early literatures, folds of regional dimension are not noted. It appears probably due to its homoclinal nature of litholayers. Physical inaccessibilities, thick
forestation, lack of proper road communication were some of the factors why detail structural mapping was not done. The classical MFT, MBT and MCT along with Lumla Thrust as tectonic window are well demarcated by most of the early workers mentioned in chapter 2 and under thrust system of present chapter. Srivastava et al. (2011) have suggested SeLa Thrust and Tawang Thrust based on satellite imagery within the hanging wall zone of the MCT. Both SeLa and Tawang thrusts are parallel to MCT and they constitute a north dipping imbricate thrust. Recently Yin et al. (2010) have suggested that the MCT is a folded thrust belt with pronounced ductile component and strain rate is increasing towards MCT zone between HHS and LHS. They have proposed SeLa Synclinorium at a higher structural level with a NE-SW axial trend and its extension is shown both towards Bhutan and China counterparts. Similarly, at the lowest structural level near Bhalukpong another regional anticlinal structure is delineated. In the present work, two more map scale anticline and synclinal fold structures are established within the HHS between Lumla and Tawang areas.

Yin et al. (2010) have mapped the western part of Arunachal Himalaya of India and the neighbouring countries Bhutan and Tibet to the west and north respectively. On regional scale they have suggested a synclinorium fold structure passing through SeLa and named as SeLa Synclinorium. This is largely a recoincence type of study and structural data input is insufficient to suggest anything about its nature and geometry. The trace of the synclinorium is curviplanar passing through Sekteng STD Klippe of Bhutan and SeLa Pass of India. The axial surface is traced looking like an open ‘S’ type which may be indicate that the regional fold is probably affected by subsequent deformation during Himalayan orogeny itself.

However, the present study substantiate the existence of the regional fold with detail structural data input into the field and laboratory systems through stereoplots, field plots and mesoscopic to microscopic structures available for observations at different stages. In SeLa
pass, all the lithounits are showing near vertical to steep dip towards N or NNW direction and away from SeLa pass towards Tawang. The generalised dip of the litholayers are moderate (≈ 60°) towards S or SE. The reversal of dip either roughly north or south is observed in the highly vulnerable sliding zones near Jung and Jaswantgarh where metabasites are dominant than the other lithounits. Small scale fold structures and other planar and linear fabrics are well documented they probably portray the nature and attitudes of the large scale structure.

Another two relatively large antiform and synforms are established in between Tawang and Lumla. The hinge zone of the antiformal structure is located at 7 km before

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Fig. 3.57 (a-e) Stereoplots from different limbs of anticlinal and synclinal structures of Lesser and Higher Himalaya. (a) Plots of the poles of S1 (=CS2) of NW limb of anticline near Tawang area (HHS); (b) Plots of the poles of S1 (=CS2) SE limb of the anticline near Tawang area (HHS); (c) Plots of lineation L2 (open circle) and L3 (open triangle) from HHS; (d) Plots of the poles of S1 (=CS2) of NW limb of synclinal structure near Lumla (LHS); (e) Plots of lineation L1 (closed circle), L2(open circle) and L3 (open triangle) from LHS
Lumla and axial trace is observable at high angle. All the litholayers of the HHS is dipping towards Tawang Town at relatively high angle in the roughly East to SE direction, strike being NNE to NE. Reversal of dip towards NW to NNW is shown by lithounits at relatively low angle. The asymmetry of the anticlinal fold shows top to the SE vergence. The dominant planar fabric (CS₂) is plotted in the stereonet and attitudes are shown in figure 3.57 (a-e). According to the plot, the βCs₂ for NW limb of the antiformal structure is 30⁰→303⁰ and for SE limb it is 32⁰→128⁰.

Further west, the synformal structure is worked out and the westernmost limb of the fold marks the Lumla Thrust. Axial orientation of the synform is parallel to the orientation of the associated antiform discussed above. The frequent changes in attitudes of the lithological layering cum bedding are due to second order folds on the limbs of the major synclinorium. The contact zone between Lumla Formation and HHS is very sharp and HHS is rolled over the Lumla Formation with sinistral sense of movement. The litholayers of HHS is almost vertical at the thrust zone. Lithological variation, grade of metamorphic differences placement of older HHS over the younger LHS indicate thrusting movement and conventionally this discontinuity is marked as Lumla Thrust, a tectonic window enclosed within HHS.

The deformational fabrics of Lesser Himalayan Sequence as well as Higher Himalayan Sequence are tabulated in table 4.1.
Table-4.1

<table>
<thead>
<tr>
<th>Himalayan episodes</th>
<th>Deformational events</th>
<th>Structural identities</th>
<th>Vergence-shear</th>
</tr>
</thead>
<tbody>
<tr>
<td>Prehimalayan</td>
<td>D1</td>
<td>Intrafolial, rootless, isoclinals, folds (F1) with attendant axial planar foliation (S₁), preserved as relict in BG and associated metasedimentaries and metavolcanics.</td>
<td>Top to the NE to E shear sense</td>
</tr>
<tr>
<td>Synhimalayan</td>
<td>D2</td>
<td>Tight to isoclinals, often asymmetric to overturned F₂ folds with associated regionally penetrative shear foliation (CS₂), fold axes are plunging NE and/or SW at low to moderate angle; stretching mineral lineation (L₂), lots of shear sense indicators marking S or SW vergence,F₁ and F₂ folds are co axial and interference pattern is rarely hook shaped (pattern-3)</td>
<td>Top to the SE to SW vergence</td>
</tr>
<tr>
<td>Synhimalayan</td>
<td>D3</td>
<td>Open to close asymmetric F₃ folds with occasional development of strain slip cleavage, fracture cleavage; crenulation lineation and triation (L₃), F₂ and F₃ folds are non coaxial, interference pattern 1 and 3 are marked by F₂ and F₃.</td>
<td>Top to W to SW vergence</td>
</tr>
<tr>
<td>Late Synhimalayan or Posthimalayan</td>
<td>D4</td>
<td>Brittle shears, faults, fractures, joints and rarely kinking with axial orientation N-S direction.</td>
<td>Top to E or SE</td>
</tr>
</tbody>
</table>

3.3 **THRUST BOUND ARCHITECTURE**

A wide spectrum of geodynamic architecture of Himalaya 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 Himalayan Crystalline (HHC) or Greater Himalayan Sequences (GHS), 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 (OH); 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 (STDF), of Burchfiel et al. (1992), which has brought the HHS into contact with the unmetamorphosed Tethyan Sedimentary Sequence of the Tibetan plateau (Visona and Lombardo, 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 mtamorphites of the Lesser Himalayan Sequences (Yin et al., 2006; Bhattacharjee and Nandy, 2008). However, HHS is considered as the oldest lithotectonic unit forming the basement with ortho and para gneisses. 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 outh. 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, whether finally merge into IMMB is another aspect to be looked into. Sarma et al. (2011) have discussed thrust bound architecture of the Eastern syntaxial bend and a brief discussion is made relating to correlation and coordination of the thrusts between the western and eastern sectors of the Mishmi block of Arunachal Himalaya.

The concept of MFT, TT (Tipi thrust), MBT, MCT and THT of Western Arunachal Himalayan Block (WAHB) is relooked into and attempted to establish that the conventional thrusts like Mishmi thrust, Lohit thrust and a number of thrusts noted by different workers such as Roing / Tezu thrust, Lalpani thrust, Tidding thrust, Walong thrust etc., of the Eastern Arunachal Himalayan Block (EAHB) are not the continuation of the thrust systems of WAHB, rather EAHB (i.e. Mishmi Block) is a foreign block now juxtaposed like a tectonic roof over the two pillars like WAHB and IMMB (Sarma et al., 2009).

In Bhalukpong – Bomdila – Tawang sector of western Kameng and Tawang districts of Arunachal Pradesh, a series of thrust bound sequences from lower to higher structural level are observed and they represent counterpart of Indian plate from south to north. After collision between India and Asia, the northern margin of the converging Indian crustal plate witnessed evidences of intensive deformational impacts resulting in a number of thrusts of imbricate morphology. Stack of such thrust bound slabs ultimately gave rise to Himalayan architecture (Molnar, 1984). From collision zone in the north to the foreland part thrust system display an order of young from 22 Ma to 1 Ma. Placement of major thrust is less complex and confusing along Bhalukpong – Tawang sector in comparision to the eastern sector of Arunachal Himalaya (Fig.2.1) (Sarma et al., 2011).

At the lowest structural level near Bhalukpong, Yin et al. (2006) suggested a fold structure (Bhalukpong anticline) of isoclinal geometry and that marks the MFT (= HFT, =
NPT – North Pasighat Thrust). Almost north dipping Tipi Thrust (TT) (27°01’39’’N: 92°36’37’’E) separates Pliocene – Pleistocene (Subansiri and Kimin Formation) from Miocene Dafla Formation to the hanging wall side. The conventional MBT is traceable at 27°05’20’’N: 92°35’18’’E and footwall side is occupied by Eocene marine and volcanic strata bound sequences. Another opinion is also observed that the MBT rather constitute a zone, forming lower MBT and upper MBT and the latter separates Permian sequences from overlying Proterozoic Bomdila Gneiss (augen gneiss dominating) and Rupa Group (phyllite, quartzite, metavolcanics and carbonate dominant group; referred to as Tenga formation or probably Dedza formation; Buxa- Miri Group of Nandy et al., 1975).

The contact between Rupa Group and Bomdila Gneiss may be treated as a thrust contact and named as Bomdila Thrust (BT) which is continuing further north east. The BT is passing through Siang, Dibang and Lohit sectors. The tectonic contact between Lesser
Himalayan Sedimentary Sequence and Lesser Himalayan Crystalline is named as Mahabharat Thrust in Nepal (Gehrels et al., 2003), hence, Mahabharat Thrust can be equated with Bomdila Thrust of WAHB. Further north of Bomdila, classic MCT is marked at \(27^\circ 22'42''\text{N} : 92^\circ 13'54''\text{E}\), around 4km from Dirang on way to Tawang and diagnostic garnet – kyanite – staurolite bearing schist, leucogranite, garnetiferous amphibolite, calc – silicate rocks, quartzofeldspatic gneiss and migmatites form “SeLa Group” structurally above the garnet – kyanite – staurolite bearing schist, phyllite, metavolcanics and micaceous quartzite sequences of the Dirang Formation. Formation of hot spring along the interface between SeLa Group and Dirang Formation is another signature of the presence of the notable thrust MCT (= Dirang Thrust). MCT in this area is 5-7 Km zone rather than a single line (Bhattacharjee & Nandy, 2008) similar to that of MCT zone of Bhagirathi valley (Metcalfe, 1993). Another tectonic contact between Lumla Formation and SeLa Group is traceable at 1 km ahead of Gipsu, WNW of Tawang and is designated as Lumla Thrust (LT) (lower boundary at \(27^\circ 33'14''\text{N} : 91^\circ 45'33''\text{E}\); 2397m) and the upper boundary is marked at 7km at a higher structural level \((27^\circ 33'32''\text{N} : 91^\circ 43'13''\text{E})\). The Lumla unit has been referred to as tectonic window and conventionally designated as Lumla Formation (Tripathy et al., 1979; Yin et al. (2006) and Bhattacharjee & Nandy (2008) have designated this rock unit as tectonic window and conventionally designated as Lumla Formation. To the north of Lumla Thrust, another thrust is marked and this is the last thrust of the Indian subcontinent at Zimithang as the “Zimithang Thrust” (ZT) (= Kaktang thrust of Bhutan; Gansser, 1983), which separates two distinct sequences of rocks; mylonitic gneiss to the north and garnet- biotite- quartzo feldspathic gneiss, sillimanite-kyanite garnet schist/gneiss to the south.

The original relationship between gneiss and metasedimentary metavolcanics cannot be determined as both the units are penetratively deformed (Yin et al., 2006), but the
present study has unravelled the presence of a conglomerate near Dedza (27°12′27″N; 92°18′15″E) and named as Nagmandir Conglomerate separating Bomdila Gneiss and Rupa Group (=Tenga Formation= Dedza Formation, which is equivalent to Bauxa Formation), showing numerous pebbles of limestone, phyllite and quartzite. This is a positive signature of old and young sequences. Another conglomerate is traceable at 5 km ahead of Shergaon, named as Shergaon Conglomerate (27°10′53″N; 92°18′15″E), which separate Rupa Group from Dirang Formation. The Rupa-Shergaon road is passing almost along the strike of the conglomerate. This conglomerate also encloses stretched pebbles, cobbles, quartz sericite schist and carbonate materials. From the disposition of the conglomerate in both the area near Nagmandir as well as Shergaon, it is confirmed that the Tenga Formation is older than the Dirang Formation as well as Bomdila Gneiss.

Recently Goswami et al. (2009) have discussed the strategy of placement of MCT and MBT and according to them structural position of MCT is found to be ambiguous although it is defined as a metamorphic discontinuity separating low grade Dirang Formation from medium to high grade SeLa Group (Kumar, 1997; Yin et al., 2006; Bhattacharjee and Nandy, 2008). They have further suggested that Bomdila Gneiss, Dirang Formation and SeLa Group may be categorised under Main Central Thrust Zone (MCTZ). The so-called THS in Arunachal Himalaya is doubted because of their scattered behaviour, devoid of fossils and absence of typical Tethyan sediments. Therefore, it is a matter of high speculations only.

3.4 KINEMATIC ANALYSIS

Consequent motion model prepared by many workers are mostly confirmed in the Central Himalayan belt (DeCeles and DeCeles, 2001; Avouac, 2003). A large number balanced cross sections are worked out in the Himalayan belt of western and central
Himalaya but in case of northeastern Himalaya, it is rarely studied. As noted by Yin et al. (2010), the large scale structure of the most active orogenic belt is described as a ‘first order’ by doubly vergent critical wedge concept (Willett et al., 1993; Batt and Braun, 1997) the upper and middle parts of the crust of the Indian underthrusting pro-plate is effectively decoupled from the underlying mantle which undergoes continental subduction underneath the retroplate overthrusting mechanism is referred to as ‘out of sequence’.

The Himalayan orogeny is substantially characterised by a north dipping, south vergent crustal scale thrust sequences. The main notable thrust systems which set the limit of different sequences from south to north are Siwalik foreland fold and thrust belt (SFFT) between most popular MFT and MBT, the metasediments and metavolcanics between MBT and MCT. The Greater Himalayan Crystalline thrust sheet with overlying Tethyan sequences, separated by STDS from Tibetan Himalayan zone. Burchfied et al. (1992), Hodges (2000) have advocated that MCT and STDS were simultaneously activated during Middle Miocene time and the southern fold belt sequences were activated at a later date. Thus, apparently it has been referred to that all the conventional MFT, MBT and MCT branch at depth to a single major mid crustal decollement. The main Himalayan thrust is characterised by a ramp-flat geometry probably with two ramps.

The LHS forms a crustal scale antiformal stack or duplex (Decelles et al., 2001), on top of which Klippe of greater Himalayan rocks are locally preserved in synclinal structures. Convergency rate varies from 13 – 21 mm per year and there is an increasing convergence rate from west to east (Billem et al., 1997). According to Decelles et al. (2001), the convergency rate varies from 5 – 15 mm per year during activation of MBT and MFT at 5 Ma and 2 Ma respectively.
Thus all the thrust models out of sequence thrusting, overthrusting and undreplating are not unambiguous. It is also apparent from different observations that the thermotectonic model is more and more complex in case of LHS.

3.5 DISCUSSIONS

It is attempted to have a synchronization of some of the early worker’s observations to draw a logical conclusion here in the present study area. Microstructural identities indicate that intensive mylonitic fabric of Synhimalayan orogeny were deformed by crystal plastic and strain softening mechanism under low to moderate pressure – temperature conditions within lower to middle part of the amphibolite facies (Mazumdar et al., 2014). Computed strain related datasets are populated in the flattening field hints moderate to high shear strain. Based on vergence pattern of small scale folds of different generations and scales, the sense of asymmetry is worked out and it is observed that Prehimalayan and Synhimalyan structural fabrics are showing top to the SE to SW through S sense of shear. On the regional scale, slip vector may be considered as top to the south sense of tectonic transport. This kinematic direction coincides with the regional kinematic directions of MFT, MBT and MCT (Yin et al., 2010).

It is inferred from the present study that the rocks of the western Arunachal Himalaya in the Bhalukpong – Tawang sector represents part of the Indian continental crust displaying compressional - collisional tectonism between Indian and Eurasian plates in a near horizontal tectonic setup followed by stack of intensive thrusting where rotational axes coincides with the x-direction of maximum extension.