Mylonitic volcanics near Puging, Upper Siang district, Arunachal Pradesh: Evidence of oblique-slip thrusting

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The Abor volcanics of the continental flood basalt affinity are extensively exposed in different parts of the Siang valley. These are associated with Yinkiong Group of rocks of Paleocene–Eocene age and represent syn-sedimentary volcanism in a rift setting. Subsequent folding and thrusting of the Siyom and Rikor sequences above the Yinkiong Group of rocks represent changes from syn-to-post collisional brittle-ductile tectonic episodes. Mylonitic Abor volcanics in the thrust contacts are studied at several locations in the north and south of Puging in the Siang valley. Both the Abor volcanics and associated Rikor and Yinkiong Group of rocks preserve meso to micro-scale fabric asymmetries indicating that the thrust contacts are shear zones of brittle-ductile nature containing mylonitic textures of high shear strain. Two distinct hitherto unrecognised shear zones in the north and south of Puging are named as North Puging Shear Zone (NPSZ) and South Puging Shear Zone (SPSZ). The kinematic indicators along the thrust contact indicate oblique slip thrusting of the Rikor and Siyom thrust sheets above the Yinkiong Group of rocks. This paper provides field evidence proving that the compression due the Burmese plate made oblique slip thrusting and zones of mylonitised volcanics possible and associated metasediments were formed. The kinematic indicators in the NPSZ and SPSZ respectively indicate top-to-SSE and top-to-NNW sense of shears.

1. Introduction

In the Siang valley, mafic Abor volcanics are exposed in a NW–SE trend from Puging to Yinkiong and this trend changes to N–S along Yinkiong to Pangin (Singh 1993). The Abor volcanics which are associated with Yinkiong Group of rocks are considered to be the youngest volcanic activity in the Siang valley of eastern Arunachal Pradesh (Tripathi *et al.* 1979, 1988; Singh 1984, 1993, 2007; Acharyya 1994; Kumar 1997; Acharyya and Saha 2013). There are a number of studies describing the compositional variations of different phases of intrusion, distributions and physical descriptions of the Abor volcanics (Jain *et al.* 1974; Bhat 1984; Roychowdhury 1984; Singh 2006). Tripathi *et al.* (1988) assigned the Eocene age for the Abor volcanics on the basis of fossil records from the *Dalbuing* area of Yamne valley. Towards the south of the Siang valley, the volcanics are folded and towards the further south, these are exposed against the younger Siwaliks along a splay of Main Boundary Thrust (MBT) (Acharyya and Saha 2008). In the extreme south of Puging, Abor volcanics are intermixed with the green and purple shales of the Yinkiong Group, while in the north and south of Puging, the volcanics are intrusive into the Rikor Group of rocks. It is important to note that the syn-sedimentary volcanism in the sediments of Yinkiong Group of rocks of Eocene age and intrusion of the Abor volcanics or its equivalent in the north of Puging may

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represent two phases of the intrusion history. The syn-sedimentary volcanism during Eocene (Yinkiong Group) and intrusion into the Rikor Group are followed by post-collisional (India–Asia) episodes of folding and thrusting. The shear zone affected both the intermixed and intrusive Abor volcanics in the south and north of Puging, during a phase when the folded thrust sheets along the Siang Valley were already in place with steeper western and gentler eastern limb. The quartzites of the Rikor Group are fine grained, massive and occasionally micaceous, while the dolomites are grey, siliceous and banded. They are thick and grey-black to pinkish in colour. The mafic volcanics intrude the dolomite–quartzite sequence and elsewhere a number of meso-scale sympathetic shear zones are observed along the contact. The volcanics along with the dolomites and quartzites are mylonitised and are metamorphosed to chlorite schist. A NNW–SSE trending shear zone is located at 11 km north of Puging (SW of Goging or NW of Bomdo; figure 1). This shear zone is referred to, here, as the North Puging Shear Zone (NPSZ). This shear zone is traced further south along the thrust contact of the volcanics with the rocks of Boleng and Geku formations. The thrust contact of the limestone–quartzite–phyllite sequence of the Pangin Formation is mapped (lithologically, the Panging Formation of the Rikor Group differs from the Boleng Formation as it is limestone dominant compared to quartzites and also consists of minor phyllite bands) (Singh 1993) with the volcanics. Along Doteng Korong Nala in the south of Puging, another zone of mylonitisation of volcanics is mapped and this shear zone is referred to, here, as the South Puging Shear Zone (SPSZ). It is important to note that the trend and sense of the SPSZ are similar to another shear zone located NNE of Goging (figure 1). On the other hand, authors have also mapped mylonitisation of the volcanics along the thrust contact with the rocks of the Pangin Formation at Sisi Nala, along which the Siang River takes a 90° swing in

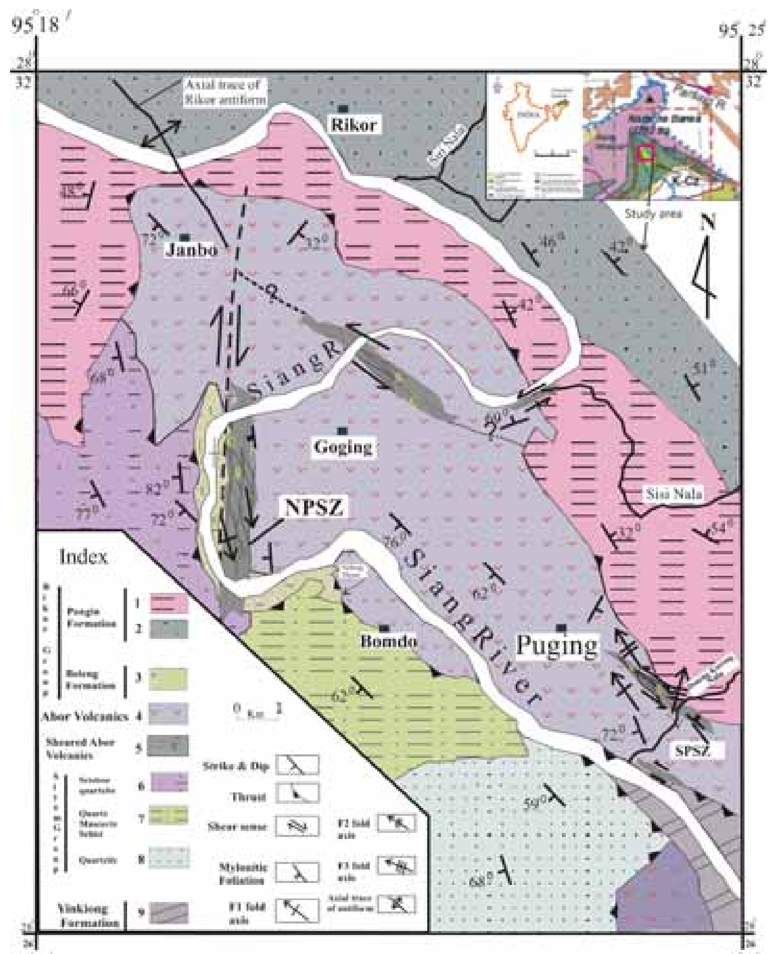

Figure 1. Geological map of the area (inset: the map of India and part of eastern Himalayan syntaxis, modified after Yin *et al.* 2010). At 11 km north of Puging, the contact between the Abor volcanics and rocks of the Boleng Formation indicated by N–S trending dextral shear zone. At half km south of Puging, the contact between the Abor volcanics and rocks of Pangin Formation show another NW–SE trending sinistral shear zone. Pangin Formation: (1) phyllite with dolomite, (2) limestone and quartzite. Boleng Formation: (3) muscovite schist, quartzite and limestone. Other lithology symbols as depicted in the index.

its course (figure 1). It is important to note that the shear zone at the north of Goging affects the dolomites and phyllites of Boleng Formation and various kinematic indicators represent a top-to-NNE sense of shear. Another shear zone affecting phyllites and sandstones of the Yinkiong Formation is also shown in figure 1. In all these zones, the early brittle phase (as the volcanics emplaced during a rift setting indicating a tensional phase) are overprinted by a ductile phase. The thrusting of the quartzite–dolomite sequence above the volcanics in the NPSZ is represented by a zone of mylonitisation where top-to-SSW shear senses are recorded (figures 1 and 2a, b), whereas in the SPSZ, the sense of shear is top-to-NNE (figures 1, 2c, d and 6). These shear senses indicate that mylonitisation of volcanics with opposite shear senses are the result of WNW–ESE compression with both dextral and sinistral senses (figure 6). It is important to note that the continental collision between India and Asia at the eastern Himalayan syntaxis might have initiated after 65 Ma (Ding *et al.* 2001). The initial phase of rifting due to east–west extension witnessed coeval volcanism and sedimentation. Subsequently, the rift closed and thrust arcuation at the Siang window was influenced by subsurface indenture of the northeastern edge of the buried Indian basement over which the pile of Himalayan nappes climbed (Saha *et al.* 2012). The architecture of the Siang antiform is further modified by the impact of the Burmese plate and more evidence of ductile deformation are preserved. In the present area, the ductile thrusting is an oblique slip and the volcanics are mylonitised at several places.

The eastern syntaxis is interpreted as fast growing crustal scale antiform (Burg *et al.* 1997). The northward indentation of the Indian plate is accommodated by left slip Pai and right slip Aniqiao shear zones (Ding *et al.* 2001) or indented wedge within these strike-slip faults represent a large folded structure. On the SW of the antiform (core of the eastern syntaxis), the NNW plunging Siang antiform is also bounded by strike-slip faults on both eastern and western sides. Ding *et al.* (2001) linked Aniqiao shear zone with the Tuting–Igo Fault whereas Choudhury *et al.* (2009) linked this shear zone with Tuting–Tidding suture. In any case, the NNW plunging Siang antiform must be created with an east–west compression probably at early Oligocene. The east–west compression has to be overprinted by an ESE–WNW compression due to the impact of Burmese plate. This impact of Burmese plate coincides with the episode of post-Barail upliftment in the Naga Schuppen Belt when

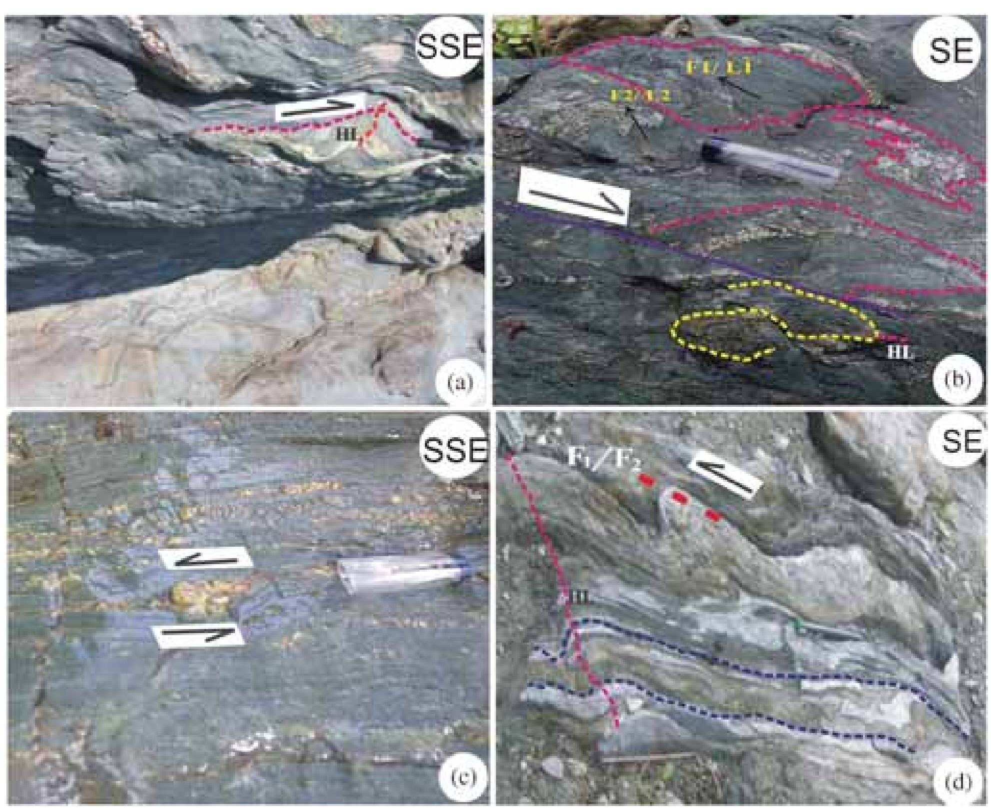

Figure 2. (**a** and **b**) Dextrally sheared volcanics in NPSZ converting to actinolite–chlorite schists. K feldspar veins are cleavage parallel and mimic shear senses. Hinge line (HL) is shown in (a). (**c**) Quartz veination in volcanics; quartz porphyroclast ('δ'-type) indicate sinistral sense. (**d**) The dolomite–phyllite co-folding in SPSZ. The movement is top-to-NW. The hinge line (HL) is shown.

the Indian plate continued to subduct beneath the Burmese plate resulting in the upliftment of Oligocene sediments. The process went on when there was a retreat of the marine basin in the north-east part of the Indian plate during the end of Oligocene to early Miocene time (Bhattacharyya 1991).

In this paper, along with the geological map of the area, two hitherto unrecognised shear zones are reported. The kinematic indicators from the shear zones helped us constrain the sense of shear in the two shear zones. Combining the structural morphology of the Siang dome (Acharyya and Saha 2008) and shear sense in the two shear zones, we are proposing a model considering the compressions related to India-Asia and Indo-Burma collisions. Finally, we are also proposing that, considering the compression directions both from the west and from the east, the two shear zones are the manifestations of oblique-slip thrusting of the thrust sheets above the Yinkiong Group of rocks, both in the north and south of Puging.

2. Mesoscale shear sense indicators

The NPSZ is located at 11 km north of Puging. The micaceous quartzite–dolomite–limestone sequence of the Boleng Formation are folded and the fold axis plunge ∼5° towards NNE (Tiwari *et al.* 1980). In the southern part of the western limb of Rikor antiform, limestones and quartz-mica-schists of Bomdo Formation (Bomdo Formation was earlier placed under Miri Group by Jain *et al.* 1974) have been folded between Rikor in the south and Paling in the north and referred to as Rikor antiform (Jain *et al.* 1974; Tiwari *et al.* 1980). The core of the antiform is occupied by dolomites and the antiform plunges about 50° towards N45°W to N50°W (Tiwari *et al.* 1980). The dolomites trend N20°E–S20°W, with a very steep westerly dip (80°). Both, the Rikor thrust sheet and the Siyom thrust sheet have oblique slip thrust contact with the volcanics. In the contact zones of the thrust sheet and the volcanics, brittle ductile shear zones with kinematic indicators like the asymmetric folding of foliated volcanics near the thrust planes, stretching lineations, pervasive mylonitisation and profuse quartz and feldspar veination in the volcanic are observed. These indicate oblique slip thrusting of the thrust sheets above the Abor volcanics. The shear zones are mapped and also shown in the cartoon (figures 1 and 6).

The volcanics in the north and south of Puging are juxtaposed against the Rikor thrust sheet (consisting of quartzites, quartz-mica schists and dolomatic limestones), which have a thrust contact with the volcanics. The asymmetry of the folds is observed and the vergence is towards SSE and SSW directions with the dextral shear senses (NPSZ). Moreover, gently SSW plunging mineral stretching lineations are observed in the NPSZ. In the SPSZ, the gently NNW plunging stretching lineations are observed (figure 1).

The Siang dome is referred as orogen transverse antiformal structure (Acharyya and Saha 2008). As thrust spacing in the western side is both narrower and steeper (see map: dip is ∼70 westerly) than the eastern side, the mode of overthrusting of both Siyom and Rikor thrust sheets above the volcanics have to be oblique slip, producing a simple shear with a moderate simultaneous pure shear component (Fossen *et al.* 1994).

The 1 km long best-exposed zone of NPSZ consists of intensely deformed and pervasively foliated Abor volcanics, recrystallised dolomites and schistose quartzites. Sheared Abor volcanics are mylonitic and brown to black in colour. In NPSZ, sheared and mylonitised volcanics show clockwise rotation with top to SSE sense (figures 1 and 2a, b). The pervasive S-C fabric is observed in the mylonite zone and the stretching lineations plunge southerly. The C-surfaces are pervasive up to the grain scale and represent the main mylonitic shear foliation. These surfaces consist of elongated actinolite, epidote, chloritoid, biotite and feldspar grains. The stretching lineations plunge at a low angle to NNW–NW direction. The C-surfaces trend NNW–SSE and are nearly vertical.

The quartz porphyroclast in figure 2(c) indicates the sinistral shear sense. The asymmetry in the folds in SPSZ (figure 2d) is towards NNW indicating a sense of movement towards NNW direction. If the eruption of the volcanics is contemporaneous with the India–Asia collision during Early Eocene (Acharyya 1994; Liebke *et al.* 2011), then it would be pertinent to assume that the volcanics are affected by later Tertiary compressive tectonics, which helped the thrust sheets to climb the orogen transverse Siang antiform. The overriding of the volcanics by the thrust sheets produced shear zones as discussed above. The intrusion of the volcanics into the dolomites and minor phyllites of the Rikor Group are common and must be a tectonic nature and the required heat for the development of ductile fabrics is due to the intense shearing. The volcanics became well foliated, deformed and invariably altered to chlorite schists. The intrusion of the volcanics into the Rikor Group of rocks correspond to the timing when the folded thrust sheets in the Siang valley were in place and further affected by the impact of the Burmese plate. Therefore, this phase of intrusion and shearing of the volcanics must be younger than the syn-sedimentary volcanism observed in the Eocene sequence of Yinkiong Group of rocks.

The conjugate sets of joints in the quartzites are observed which represent a 'δ'-type shape. The angle between the conjugate sets being 60° represent both dextral and sinistral senses. These joints may be initially tension gashes and subsequently rotated due to folding. Some epidote veins are also observed. Quartz veins in the volcanics are folded depicting the intensity of shearing where initial length became reduced and finally sheared out at the thinner limbs. These veins are clearly foliation or cleavage parallel and are folded together with the volcanics. It is noteworthy that quartz-calcite veination in volcanics are also reported in Tuting metavolcanics (Saha *et al.* 2012). Cleavage parallel veins in the metavolcanics represent a contemporaneity of the veination and folding, while cleavage transacted veins are clearly a later phenomenon. Cleavage transacted veins are at high angles to the foliation. In the present area, the Abor volcanics are metamorphosed under greenschist faces condition. Veination is a later phase undergoing deformation along with the volcanics and quartzites. The foliation in the volcanics has provided the form surface and therefore the foliation parallel veins are observed.

The SPSZ is located about half a kilometre south of Puging. The intimate association of the quartzite–carbonate sequence (with the quartzite at the core and argillo-arenaceous rocks at the limb) exposed at the vast area of the Siang valley was earlier reported by Sengupta *et al.* (1996) and Talukdar and Mazumdar (1983). The phyllite–dolostone sequence of the Pangin Formation in the SPSZ is overriding the volcanics and the mesoscale shear sense indicators depict a top-to-NNW shear sense. The phyllite–dolostone sequence is asymmetrically folded. The tight isoclinal F_1 folds are refolded by open asymmetric F_2 folds. F_1 and F_2 are coaxial and axes plunge at a low angle towards NNW (figure 2d). This trend is similar to the direction of the plunge of the Rikor anticline and should share the same (episode) magnitude of compression. F_1 and F_2 folds are refolded by open warp type F_3 folds which plunge towards NNE. The shear bands in the metasediments are quartz poor (O'Brien *et al.* 1987) inclined at an angle of 30° to the C-foliation. Dextral shear bands also produced asymmetric boudinage in feldspars in metasediments. The massive quartzites of the Boleng Formation in the western part of the N–S trending shear zone (NPSZ) are steeply dipping to the west and suffer brittle deformation. Intensely mylonitised volcanics in the NPSZ are highly foliated (figure 2a, b). These metavolcanics, consisting of ductile S-C fabric and mineral assemblages, indicate they are metamorphosed under greenschist facies condition. In the NPSZ, the stretching lineations are plunging at a low angle to NNW (figure 3a). In the SPSZ, the foliations in the metavolcanics are near vertical (~85°) and the mineral lineations (XZ plane) plunge at a low angle (~15°) in the NNW to NW direction. The F1 and F2 fold axes plunge at low angles mostly to NNW direction (figure 3b).

3. Microstructures

The volcanics (actinolite schists, chlorite schists and epidote schists) and the metasediments (schistose quartzite, quartz-mica schist, muscovite-chlorite schist and abundant quartz and calcite veins) exhibit considerable fabric asymmetry. Volcanics are medium to fine grained and K-feldspars, augite, chlorite, chloritoid, epidote, and plagioclase are present. The mineral assemblages indicate an original basaltic composition metamorphosed and hydrated. Alkali feldspar phenocrysts may be dominant in the original composition of the basalt. The

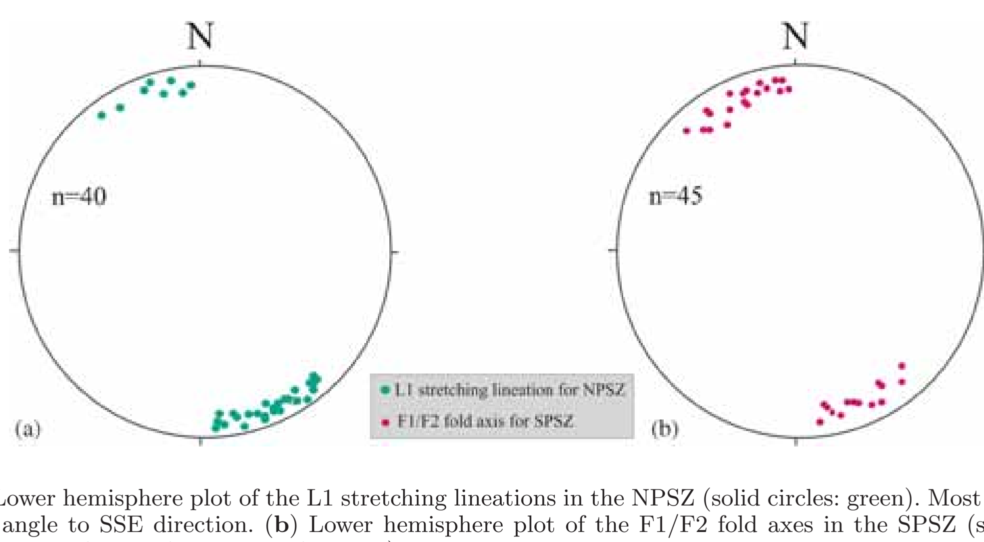

Figure 3. (**a**) Lower hemisphere plot of the L1 stretching lineations in the NPSZ (solid circles: green). Most of the lineations plunge at low angle to SSE direction. (**b**) Lower hemisphere plot of the F1/F2 fold axes in the SPSZ (solid circles: red, F1/F2 axes plunge at low angle to NNW direction).

presence of K-feldspar as medium sized grains and the minor presence of tiny plagioclase indicate that the alkali feldspars might have replaced the plagioclase grains. However, in the mylonitic volcanics, the alkali feldspars, pyroxenes, actinolites and chloritoids appear as porphyroclasts in a matrix dominated by feldspar, pyroxene in a calcareous and cherty matrix. The effect of hydration is responsible for the epidotisation of the pyroxene. The feldspars are also serisitised. Dextrally rotated δ-type winged chloritoid prophyroclasts are observed in NPSZ in the XZ plane of finite strain ellipsoid. The wings are straight and show right stair step geometry (figure 4a). Actinolites are also rotated clockwise (figure 4b). The associated matrix minerals are also sheared. Chloritoid porphyroclasts in the matrix are sinistrally rotated in SPSZ with top-to-NW sense. In the SPSZ, the sigmoidal alkali feldspar porphyroclasts also show top-to-NW sense (figure 4c). Rotating chloritoids in the SPSZ are transacted by a micro shear plane which causes a displacement of the fragments. The asymmetry of imbrications or sense of displacement is synthetic to the bulk shear sense (Passchier and Trouw 1996) (figure 4d). Crenulations in the phyllonites are common both in the NPSZ and SPSZ. The asymmetry shows both clockwise and anticlockwise rotations. Highly crenulated fine-grained phyllites exhibit asymmetric crenulations with distinct NW–SE orientation Veins of K-feldspar, epidote, calcite and adularia are observed in the sheared Abor volcanics. Pyroxene altering to epidote might have continued for a considerable duration.

4. Oblique-slip thrusting

The contact between the volcanics and the Rikor Group of rocks indicate the Abor volcanics being sheared and mylonitised. The increase of the fold asymmetry near the thrust plane is remarkable both in NPSZ and SPSZ (Dubey 2014). This phenomenon is demonstrated through figure 5(a, b and c). In the NPSZ, the foliated volcanics are folded near the thrust contact (figure 5a), while in the SPSZ, the limestone dolomite sequence folded near the thrust (figure 5b). The asymmetry of the folds near the shear pane and fold becoming upright away from the shear plane is observed at several places (figure 5c). The arrangement of thrust sheets (Singh 1993) in the present area is shown in the cartoon (figure 6). The Siang Thrust sheet exposes the Higher Himalayan Crystallines (HHC) which was referred as the Siang Group (Singh 1993), over the Lesser Himalayan sequences along the MCT. The HHC is very thick in the western limb of the Siang

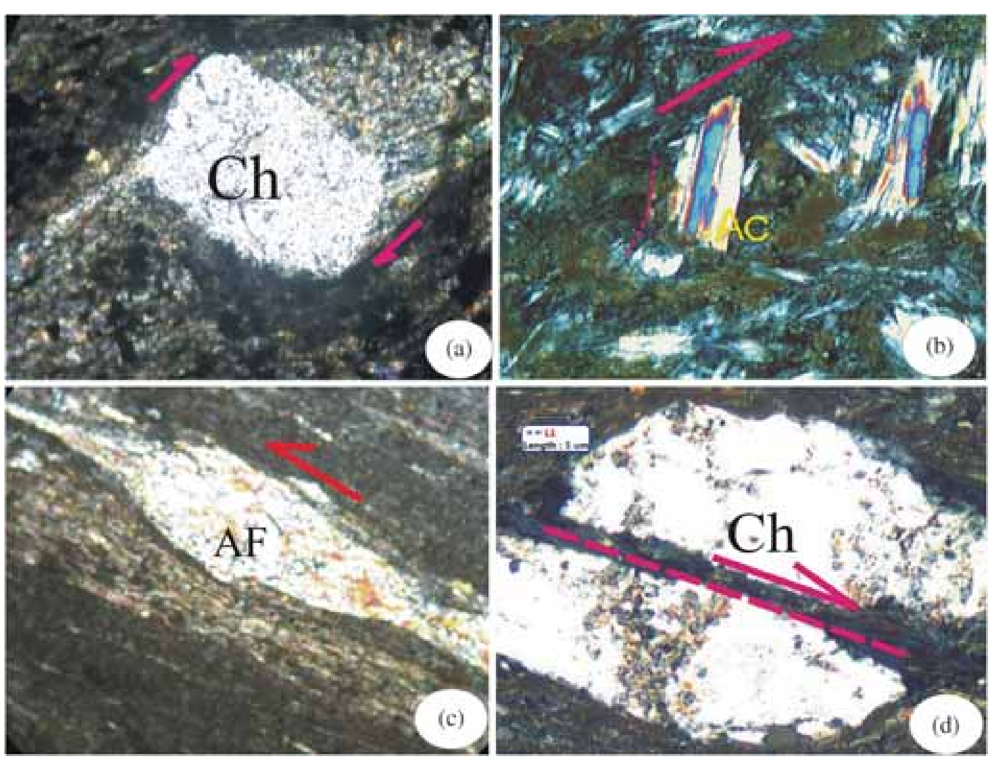

Figure 4. (**a**) The 'δ'-type winged chloritoid (Ch) porphyroclast in volcanics show top to SSE sense. (**b**) Actinolite (Ac) grains showing top-to-SSE rotation in NPSZ. (**c**) Sigmoidal or parallelogram-shaped alkali feldspar (Af) porphyroclasts show top-to-NW movement in SPSZ. (**d**) Rotated chloritoid porphyroclasts in volcanics show dislocation synthetic to the direction of flow.

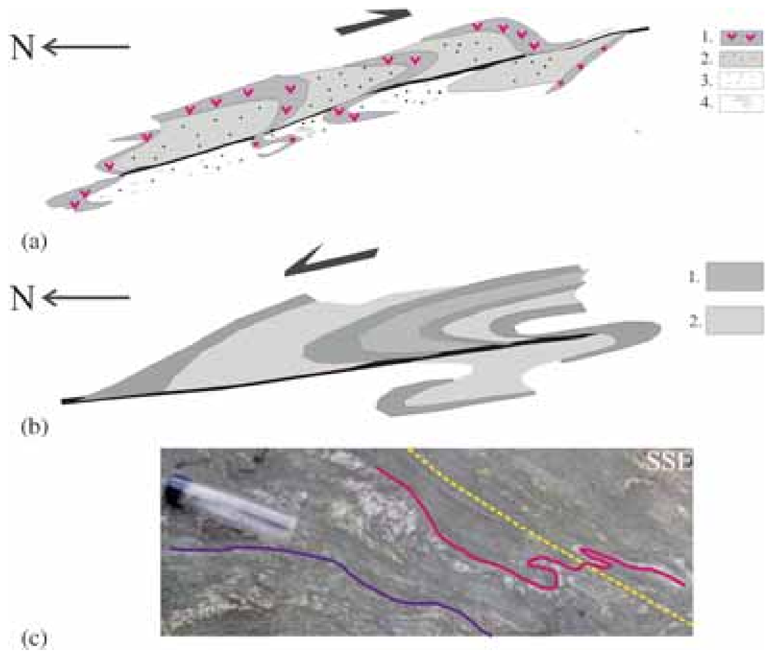

Figure 5. (**a**) Field sketch showing the asymmetric folds near the thrust plane (yellow dashed line) in the NPSZ: (1) volcanics, (2) sandstone, (3) Quartz mica schist, (4) limestone. (**b**) Asymmetric folds near the thrust plane in the SPSZ: (1) phylite, (2) dolomite. Away from the thrust plane the folds become upright (solid purple line).

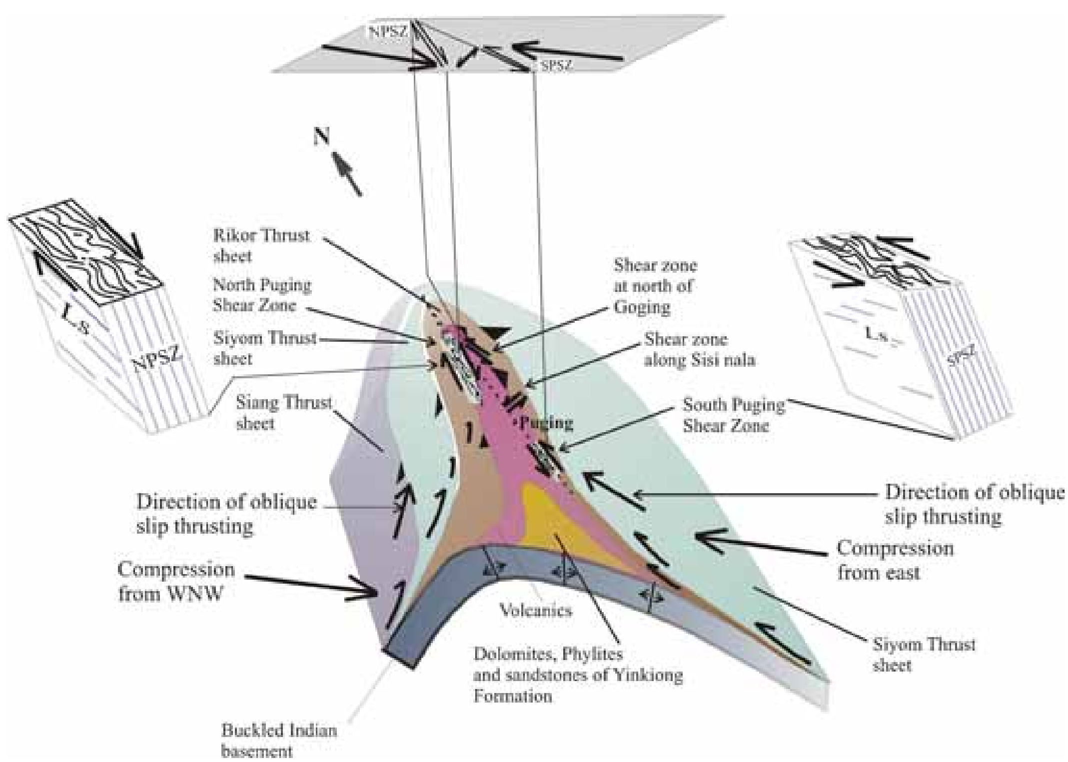

Figure 6. Aarrangements of the thrust sheets in the area (part of the Siang dome). The extension fractures in the buckled Indian basement might have provided the rift setting for the intrusion of the volcanics. The oblique override of the thrust sheets related to the transpression with a higher magnitude of compression from ESE due to Burmese plate collision. Mesoscale fabrics in NPSZ and SPSZ are shown. The compression from ENE and WNW are acting on two different planes creating dextral and sinistral shear zones are shown at the top. Directions of oblique slip thrusting shown.

antiform and its northwestern continuation in part is represented by garnetiferous graphitic schists (Choudhury *et al.* 2009). The Siang Thrust sheet in the north is in contact with the South Tibet Detachment (STD) (not exposed in the present area) (Choudhury *et al.* 2009; Acharyya and Saha 2013).

The Siyom Thrust sheet exposes low to medium grade Siyom Group of rocks tectonically below the Siang Group. In the eastern limb of the Siang antiform, the Siyom Group is represented in the lower part by augen bearing mylonitic orthogneiss within graphitic phyllites, marbles, quartzites and garnet mica schists. On the western limb, thick sequences of quartzites, biotte schists, carbonaceous phyllies and marbles with basic volcanics are exposed.

The Rikor Thrust sheet exposes the limestone, phyllite and quartzites of the Rikor Group below the Siyom Thrust sheet. The Rikor Thrust sheet tectonically frames the two sedimentary units at the core of the Siang antiform: the upper unit is Yinkiong Formation and the Lower Unit is Miri Formation. Based on its foraminiferal assemblage the Yinkiong Group is assigned an Early to Mid-Eocene age (Acharyya 1994). The quartzites of the lower unit are lithostratigraphically correlated with the Middle Palaeozoic to Lower Permian Miri Quartzites (Jain and Thakur 1978; Bhat 1984). The calcareous quartzites immediately below the Abor volcanics were dated as Late Palaeocene–Early Eocene in age, by the presence of larger foraminifera (Acharyya 1994). On the basis of this analogy, Acharyya (1994) opined that the Abor volcanics erupted in between the Late Palaeocene–Early Eocene. The calcareous quartzites and Yinkiong Formation therefore range in age from Upper Palaeocene to Early Eocene. Whether the Miri Group of rocks could be included with the Rikor Group of rocks (Jain *et al.* 1974) is, however, an open question.

The configuration as depicted in figure 6 may be due to the fact that the Indian lithospheric plate is buckled with a steeper western ramp. The eastern ramp is gentle. On the steeper ramp, the Himalayan nappes have to climb to be disposed, as shown in figure 6. The northern part of the Siang antiform is considered as the fault bend antiformal closure (Acharyya and Saha 2008). The Siang dome is also referred as a NNW plunging orogen transverse (Acharyya 2007) antiformal structure. Our field observations near Bomdo and in the north of Puging indicate that the quartzites of the Siyom thrust sheet dip steeply (∼70°) westerly, whereas in the eastern side the quartzites of the Rikor Group dip moderately (∼40°) easterly. On the map scale, the thrust spacing is closer in the western side, which indicates the western ramp is steeper. The volcanics of Eocene age have been affected as the Siyom and Rikor thrust sheets climb obliquely in response to a compression, as depicted in figure 6, which is clearly a later phenomenon. The folding and thrusting must be synchronous and followed the buckling of the Indian lithospheric plate. A second phase of shortening from the easterly direction, due to the impact of the Burmese plate, conforms to wrench dominated Sanderson–Marchini model of transpression (figure 6) (Sanderson and Marchini 1984). Our field observations suggest that the following parameters can be used to constrain the involvement of the component of transpression:

(i) obliquity of the major folds, i.e., the axis of the Rikor anticline plunging 50° to N45°W and this trend is at an angle to the axis of the Paling synform which plunges 10° to NW,
(ii) the asymmetry of the folds near the thrust contact rotation of the hinge lines of the mesoscopic folds – in the NPSZ the fold axis at an angle to the core of the shear zone (figure 2a) and becoming parallel (figure 2b) to the shear zone boundary; in the SPSZ (figure 2d) the hinge line is parallel to the thrust (Dubey 2014),
(iii) horizontal stretching lineations in the NPSZ represent a wrench transpression (Fossen *et al.* 1994), and
(iv) in the map scale, the axial trace of the Siang and Namche Barwe antiform swing from NE to NNW (Choudhury *et al.* 2009).

As illustrated in figures 1 and 6, the Siyom and Rikor Thrust sheets are obliquely overriding the volcanics creating dextral (NPSZ) and sinistral (SPSZ) shear zones in the area. The compression axis also acted on two different planes as shown in figure 6, so that two shear zones with opposite senses can develop. It is important to note that near the thrust plane the asymmetry of the fold increases and away from the thrust plane the fold becomes almost upright (figure 5c) (Dubey 2014). The mylonitised volcanics, paralleling the Sisi Nala and north of Goging, represent other shear zones trending NE–SW and NW–SE, respectively. Mesoscale shear sense indicators, both in the NPSZ and SPSZ, indicate dextral and sinistral senses. The volcanics besides being mylonitised, become hydrated and metamorphosed to actinolite and chlorite schists.

5. Discussion

The Abor volcanics are intrusive into the metasedimentary sequences of Boleng and Pangin Formations of the Rikor Group at many places in Upper Siang valley. This phase of intrusion coincides with the timing when the folded thrust sheets of Siang valley were in place. Subsequent movement of the thrust sheets due to ENE–WSW compression produced shear zones of brittle–ductile nature in the volcanics. However, neither these shear zones, nor the kinematic indicators within these zones have been reported so far. The NPSZ trends nearly N–S, while the SPSZ is NW–SE. In both the shear zones, the initial ductile phase is overprinted by a brittle deformation. The volcanics are sheared and hydrated and associated sediments have suffered very low-grade metamorphism. Effects of hydration could be observed, as the basic minerals like pyroxene have altered to epidote and actinolite. Chloritoids are also formed in the metasediments. The fabric asymmetry in the NPSZ indicates mainly dextral rotation of the grains. The dextral sense is also recorded in the mesoscale shear sense indicators. The phyllite–dolomite sequence of the Pangin Formation show F_1 and F_2 coaxial folding trending to NNW, while the F_3 fold plunges towards NNE.

It is important to note that the rocks of the Boleng Formation (Rikor Group) are exposed in the western and southwestern part of NPSZ and the Nelleng Thrust defines its boundary against the volcanics (Singh 1993). This boundary is the thrusted contact of the quartzite–dolomite–phyllite sequence of the Rikor Group and the volcanics. Field evidences suggest (figures 2 and 3) that the oblique slip thrusting of the Rikor thrust sheet above the volcanics is responsible for the development of a dextral shear zone (NPSZ). In the SSW part of the NPSZ, it is questionable whether the quartzites and quartz mica schist at Bomdo belong to Boleng Formation or parts of the Siyom Group, because the stratigraphic status of the Bomdo Formation was placed differently by different workers (Jain *et al.* 1974; Tiwari *et al.* 1980). The oblique slip thrusting of the thrust sheets created brittle–ductile shear zones in the area with top-to-SSE and top-to-NNE senses (NPSZ and SPSZ). We are proposing a transpression with mesoscale fabrics like subhorizontal to horizontal stretching lineations, obliquity of the axes of the major folds, asymmetry of the mesoscopic folds near the thrust planes and near upright nature away from the thrust and rotation of the axis of the outcrop scale folds. Buckling of the Indian basement and the development of an orogen transverse antiform represents a late phase of compression. The dip of the thrust sheets (Rikor and Siyom) on the western side is steeper and on the right side is gentler. On the map scale, the spacing of the thrust sheets is narrower compared to the eastern side. Therefore, the Siang and Siyom thrust sheets climb a steeper ramp compared to the Rikor thrust sheet. This evidence suggests that the subsurface indenture of the Indian lithospheric plate has a steeper ramp on the western side. The antiformal structure is constrained between two major faults: the Tuting–Basar dextral fault on the western side (Acharyya and Saha 2008) and the Tuting–Tidding Suture zone on the eastern side (Choudhury *et al.* 2009).

6. Regional significance

The mylonitisation of the Abor volcanic at several locations along the Siang valley mark the youngest tectonic activity related to the Indo-Burmese collision. The structures developed during the brittle–ductile phase draws special attention in regard to (i) oblique-slip thrusting of the thrust sheets and (ii) prevalence of temperatures which owe its origin to the shear heating and extrusion or intrusion of the volcanics. Although, most of the faults are mapped (Tiwari *et al.* 1980; Singh 1993; Acharyya and Saha 2008) in the area, the meso-to-microscale shear sense indicators along the fault/shear zones are not studied so far. Therefore, the present study gives a better understanding, especially about the nature of the thrust override on the buckled Indian basement (figure 6) and the roll of the regional compression constrained form the kinematic indicators within the shear zones. The authors have studied the syn-sedimentary volcanism in the downstream part of the Siang River, however, in the present area, the intrusion of the volcanics and subsequent hydration and low-grade metamorphism clearly indicate an event related to the Burmese plate collision from the ESE direction, during the early Pleistocene time.

7. Conclusions

1. The metasediments of the Rikor Group and the Abor volcanics have a sheared contact, at least, at two locations in the north and south of Puging, where the volcanics are mylonitised.
2. The mesoscopic shear sense indicators depict top-to-SSE (dextral) and top-to-NNW (sinistral) senses in the NPSZ and SPSZ, respectively.
3. The volcanic are sheared and hydrated. The thermally perturbed metasediments have undergone low grade metamorphism.
4. The Siang and Siyom thrust sheets climbed the buckled Indian lithospheric plate on the steeper western ramp and the Rikor thrust sheet on the gentler eastern ramp. The Rikor and Siyom thrust sheets override the volcanics creating dextral and sinistral shear zones. Thus, the two shear zones are the manifestations of the oblique slip thrusting of the thrust sheets from the western and eastern side.
5. The buckling of the Indian lithospheric plate forming the orogen transverse antiform is related to the collision of the Indian plate and the Burmese plate during Late Eocene–Early Oligocene or before the initiation of foredeep and development of MBT.

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