Field Structural Geological Studies Around Kurseong, Darjeeling-Sikkim Himalaya, India

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1 Introduction

Mallet (1874) divided the metamorphic rocks of the Darjeeling-Kurseong region (see Table 1) into two Formations: Darjeeling Formation of high grade garnetiferous schist, mica gneiss and the phyllitic Daling Group of rock. The pioneering geological inputs provide a detailed account of the lithology and deformation of this region (e.g., Sinha Roy 1973; Acharyya and Ray 1977; Acharyya 1989). Ray (1947) has described the Senchal Series of rocks, which includes both the Darjeeling and the Daling rocks. In the study area, the Gondwana rocks are overlaid by metamorphic rocks of the Daling- and the Darjeeling Group/Formation (Fig. 1; Lahiri 1973). Mukhopadhyay and Gangopadhyay (1971) worked in the both side of Teesta valley and found more or less the same lithology. According to Jangpangi (1972), each of the rock units are separated by thrust faults. On the other hand, Mallet (1874) suggested that the contact between the Daling and the Darjeeng is gradational. As per Ray (1947), there is no distinct separation between Daling and Gonwana at Tindharia. But Singh (1972) suggests near Tindharia the Daling rocks overlie the Gondwana rocks and they are separated by the NE trending Tindharia Thrust. The Daling Group consists of mainly slates and phyllites. The metamorphic-grade of phyllite elevates near the Tindharia Thrust (Singh 1972). This could be the effect of shear heating of the fault (Mukherjee and Mulchrone 2013; Mulchrone and Mukherjee 2015, 2016; Mukherjee 2017a, b; Mukherjee and Khonsari 2017, 2018; Mukherjee and Agarwal, submitted). The Daling Group can be recognized as quartz-chlorite schist. The Darjeeling Group can be identified as garnetiferous mica schist and mica gneiss. Especially, in the Darjeeling–Bijonbari area, such rock types are exposed (Sen 1971). The main composition of the gneiss in the Darjeeling Group

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Table 1 The stratigraphic succession of Darjeeling-Kurseong

<table>
<tr><th>Mallet (1874) Auden (1935)</th><th colspan="3">Ray (1947)</th><th colspan="2">Wager (1939)</th><th>Gansser (1964)</th></tr>
<tr><td rowspan="3">Darjeeling gneiss</td><td rowspan="6">Senchal series</td><td rowspan="3">Pelitic group (Darjeeling gneiss)</td><td>Typical coarse mica-gneiss</td><td rowspan="6">Daling series</td><td rowspan="6">Injected gneiss (Darjeeling) Dalings, belongs to Mt. Everset Pelitic series</td><td rowspan="2">Darjeeling gneiss</td></tr>
<tr><td>Flaggy garnetiferous mica- schist and quartzite</td></tr>
<tr><td>Carbonaceous mica-schist garnet rich mica-schist andcalc-schist</td><td>Garnetiferous mica-schist</td></tr>
<tr><td>Transition zone</td><td rowspan="3">Slate-greywacke Group (daling)</td><td>Golden and silvery mica-schist</td><td rowspan="3">Daling schist</td></tr>
<tr><td rowspan="2">Daling series</td><td>Greywacke-schist</td></tr>
<tr><td>Slate phyllite with occasional quartzite, and greywacke-schist</td></tr>
</table>

Reproduced from Lahiri (1973)

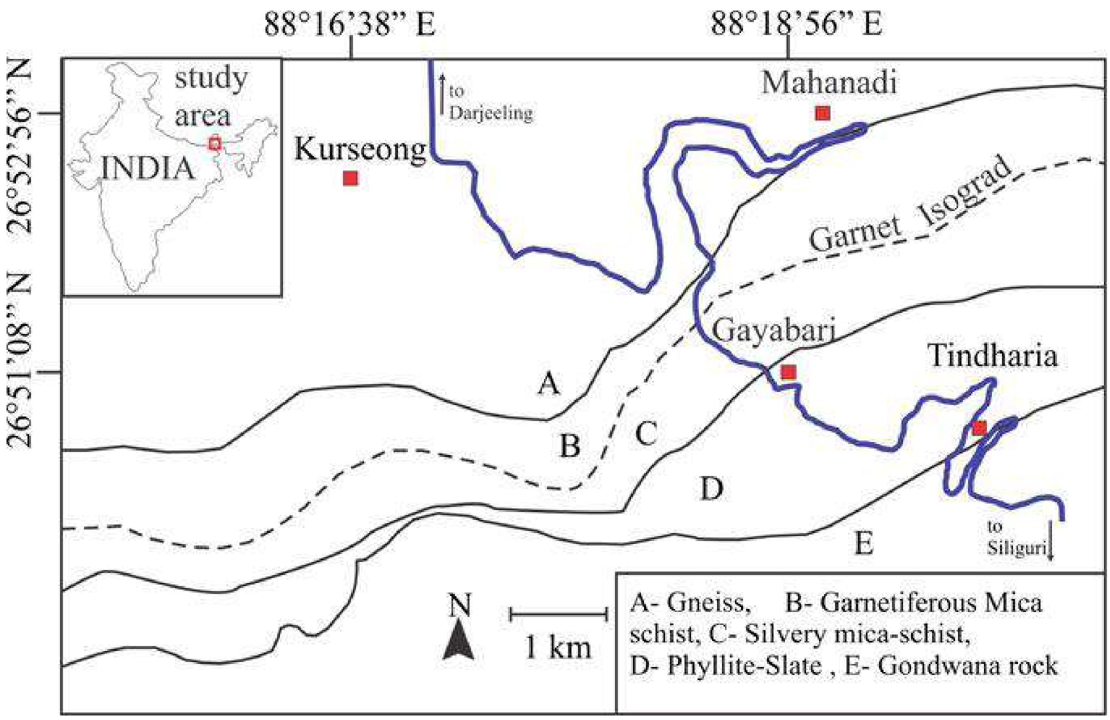

Fig. 1 Lithological map reproduced from Lahiri and Gangopadhway (1974). The garnet isograd is shown

is feldspar, biotite and occasional muscovite (Sen 1971). The Lesser Himalayan phyllites connote the sediments of the northern boundary of the Indian plate (Acharyya et al. 2017). However, different authors provided different names for the similar litho-/structural-units. For example, Bhattacharyya and Mitra (2009), and their subsequent works report that the following lithounits are present in the current study area (from S to N): Siwalik Formation, Gondwana/Buxa Formation, Daling Group with Lingtse Gneiss intrusions, Paro Gneiss, Darjeeling/Kanchenjunga Gneiss. This has been followed in Figs. 2, 3 and 4.

2 Structures

Most of the previous workers document two deformation phases. Mukhopadhyay and Gangopadhyay (1971) describe three phases of deformations. The F_1 tight folds are characterized by long limbs, axial plane schistosity and mineral lineation (Sen 1973). The inter-limb angles are <35° and these folds are mostly rootless and with smooth round hinge (Mukhopadhyay and Gangopadhyay (1971)). The D_1 is commonly confined within the banded semi-pelitic rocks (Lahiri 1973). The L_1 mineral lineations at the eastern part of the Teesta river plunge NE, but that at the

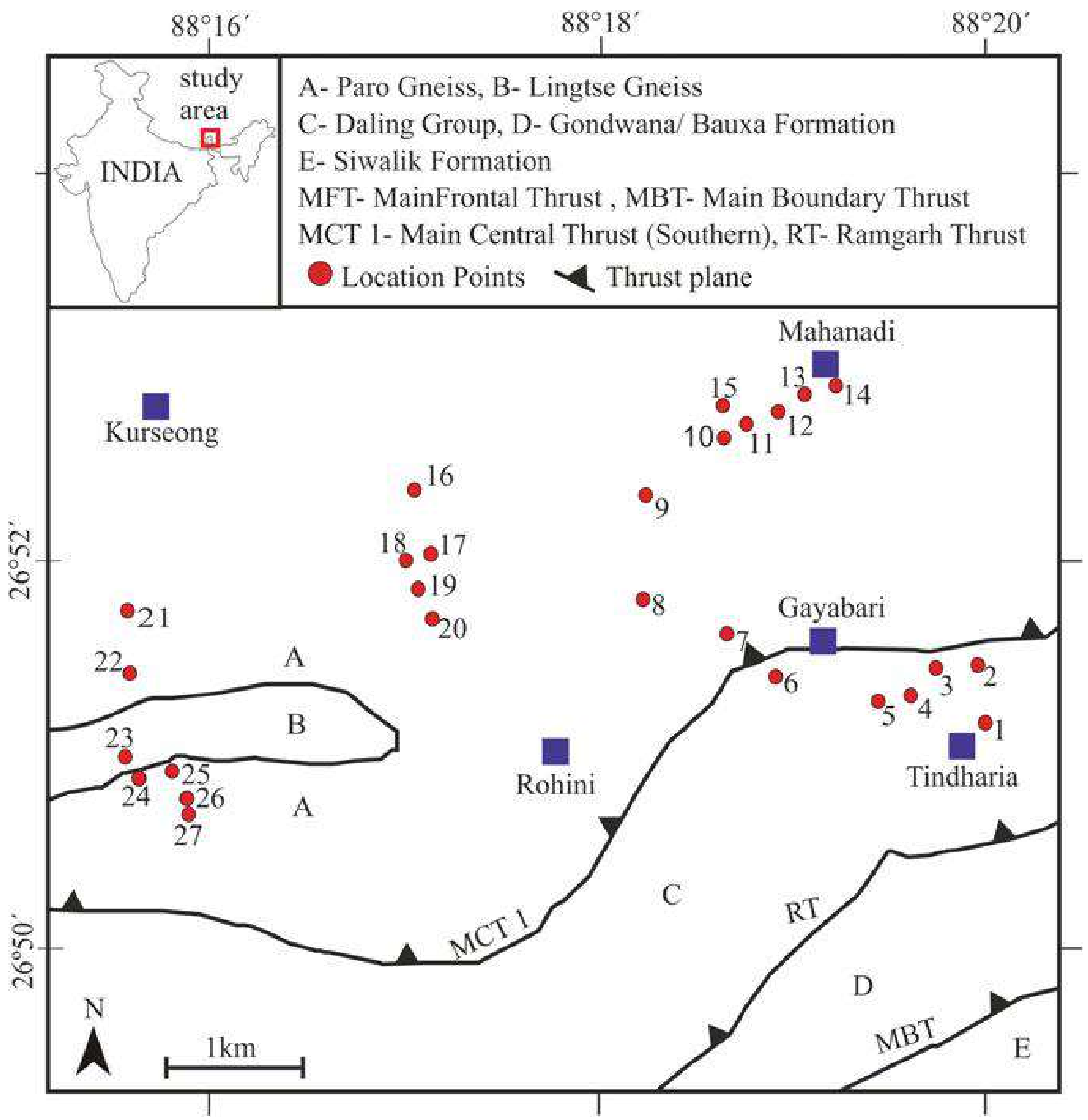

Fig. 2 Location map of the study area

western part plunges NW (Mukhopadhyay and Gangopadhyay (1971)). Minor open folds on the axial plane schistosity of the F_1 folds define the F_2 folding (Sen 1971). In Daling rocks, D_2 displays polyclinal open minor folds and pucker cleavages. The S_2 schistosity is at high-angle to the S_1 (Lahiri 1973). According to Mukhopadhyay and Gangopadhyay (1973), the second generation structures are SE plunging fold axes. Mukhopadhyay and Gangopadhyay (1973) has described the third generation structures in terms of disharmonic- and often symmetric folds. Rarely chlorite occurs along the schistosity. These fold axes plunge towards N or S. Bose et al. (2014) report a fourth phase of folding (F4) from this region.

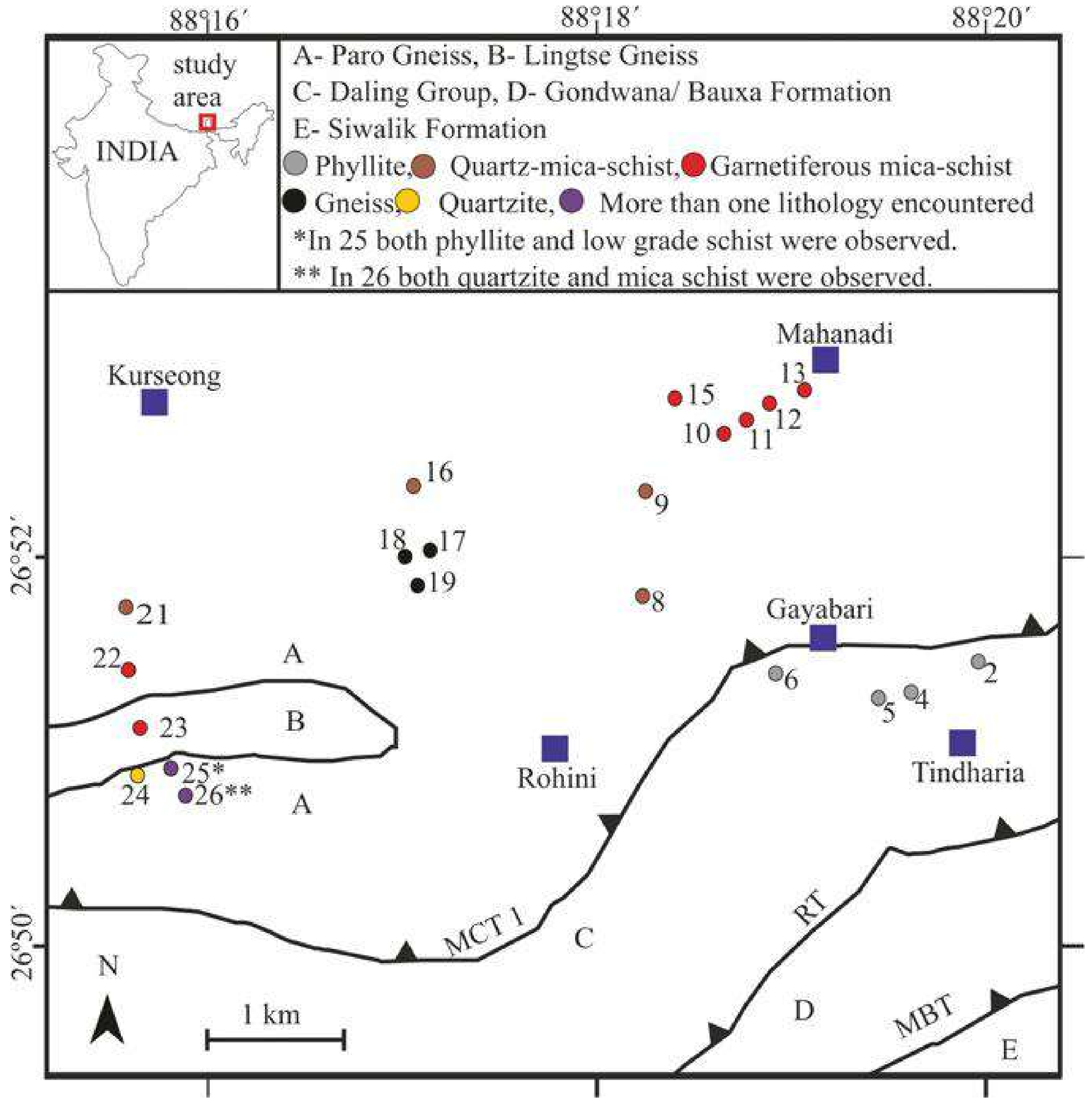

Fig. 3 The map shows lithology encountered at different locations

3 Metamorphism

Ray (1947) observes chlorite grade systematically altering to sillimanite grade towards north. While in the western part of the Teesta valley, one can observe chlorite to sillimanite transition, in eastern part staurolite and sillimanite do not appear as the index minerals (Mukhopadhyay and Gangopadhyay 1973). The term reverse metamorphism was used by Jangpangi (1972) to describe the inverted metamorphism in this region. Lahiri (1973) documents recrystallized quartz and biotite. Garnet took the longest time span to grow. Thin-section study of garnet has reveal its syn- to post-kinematic nature with respect to the F_1 and the F_2 folding. Recrystallized chlorite along the axes of the F_3-folds connotes local retrogression (Mukhopadhyay and Gangopadhyay 1973). Ray (1947) observes the metamorphic grade change towards north following a Barrovian sequence. Singh (1972) confirms from chemical

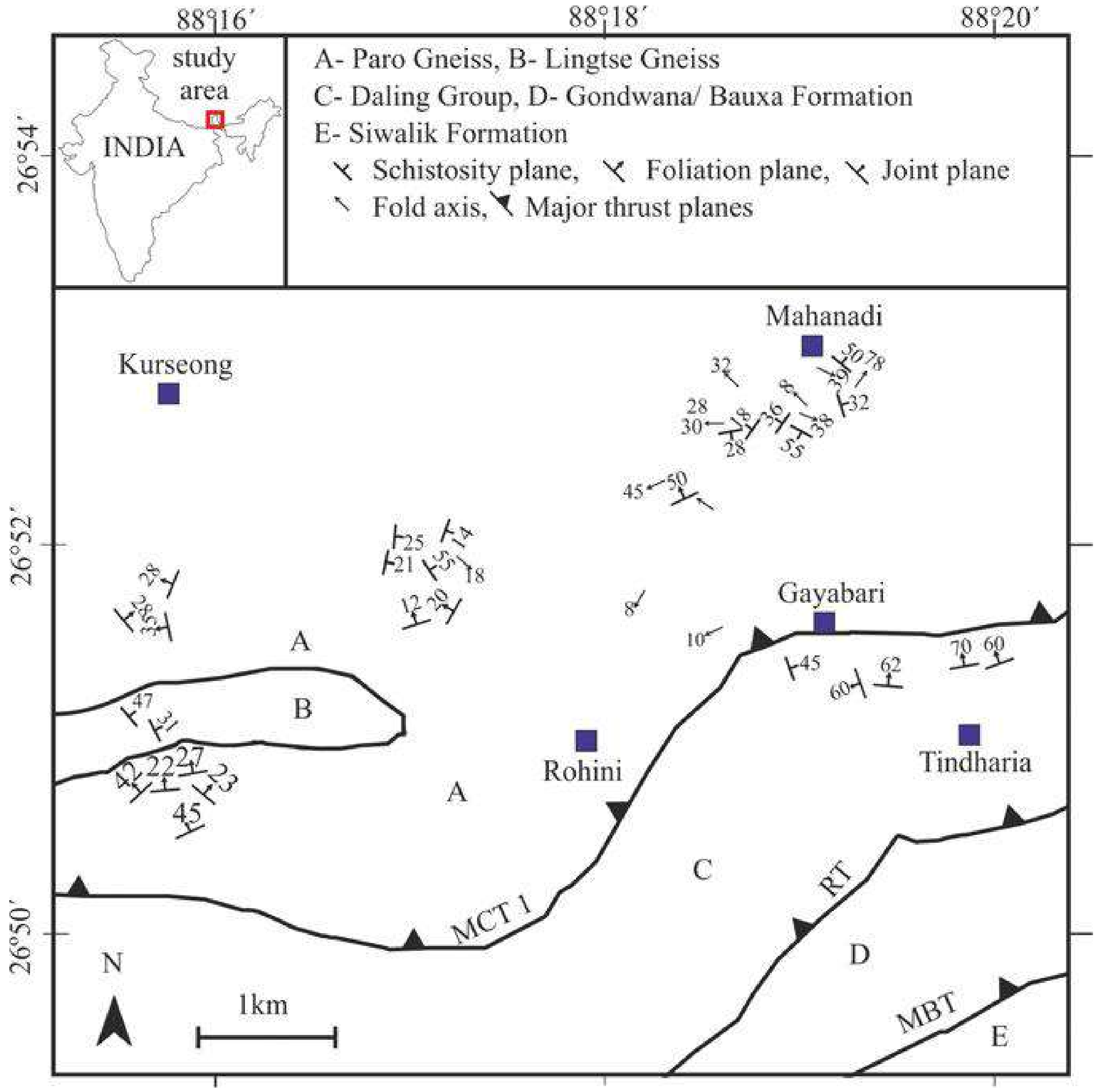

Fig. 4 Structural data plotted on the study area map

analyses that both the Daling and Darjeeling rocks are of same origin but due to heterogeneity in bulk composition the metamorphic products are different.

4 Lithologies

In the field area (Fig. 2), the lithology varies along the N-S transect. A change in metamorphic grade was also observed. Starting with phyllites near Tindharia in the southern part of the field area, up to gneissic grade of rock was encountered near Kurseong (Fig. 3). According to the classification of Mallet (1874), phyllites belong to the Daling Group of the (Inner-) Lesser Himalaya. The other rock-types, quartz-mica-schist, garnet bearing mica-schist, mica-gneiss and quartzite, belong to the Darjeeling Formation.

Phyllite (Daling Group):

Phylliteis the type lithology around the Tindharia Railway Station, in between L-1 and 5 (Fig. 4). Overall dip direction of the phylliteis towards north. The same lithology was also encountered between L-25 and 31 in the Kurseong Pankhabari road-cut section. Grain size of phyllite increases for 3 km along the road-cut section towards north. A gradual change in grade from phyllite to quartz-biotite schist happens after L-5 proceeding towards north.

Quartz-mica-schist (Daling Group):

Mica schists occur at places between Gayabari and Mahanadi railway stations (L-7, L-8 in Fig. 4). The grey coloured quartz-mica schists were defined by the spaced cleavage domain of biotite and coarse microlithon of quartz grains. Concordant quartz vein within the quartz mica schist occur near a landslide zone (L-9) at ∼2.5 km from the Gayabari Railway station towards Mahanadi. The same quartz-mica schist also occur in L-16 (∼2.3 km from the Kurseong railway station in Kurseong–Rohini road), and in L-21 (∼2.1 km from the Kurseong railway station in the Kurseong–Pankhabari road). L-24, 25 and is characterized by low-grade mica schists.

Garnet bearing mica schist (Darjeeling Formation):

Garnet appears in the cleavage domain of mica schists after L-9 towards Mahanadi. In the Tindharia-Kurseong section, garnet-bearing mica schists are black and are crenulated. Garnet also occurs within the mica schists along the Kurseong-Pankhabari road section. In L-25 and L-26 greyish brown coloured garnet bearing mica-schists are found.

Mica gneiss (Darjeeling Formation):

In the Tindharia-Kurseong section, 2 km before the Mahanadi railway station, light-coloured gneissic rocks crop out along with garnetiferous mica schist. The light-coloured units also consist of garnets. In the Kurseong–Rohini section, gneiss and mica schist occur in bands.

Quartzite (Daling Group):

The quartzite unit is overlaid by shinning greenish phyllite. Prominent foliation planes dip towards N. In L-25 and 26, more than one lithology was encountered.

5 Structures

Foliation planes in the Tindharia–Kurseong section dip towards N, NE, and SW. In Kurseong–Rohini section, they dip towards E and NW, and in the Kurseong–Pankhabari section towards NW, N and NNE (Figs. 4 and 5).

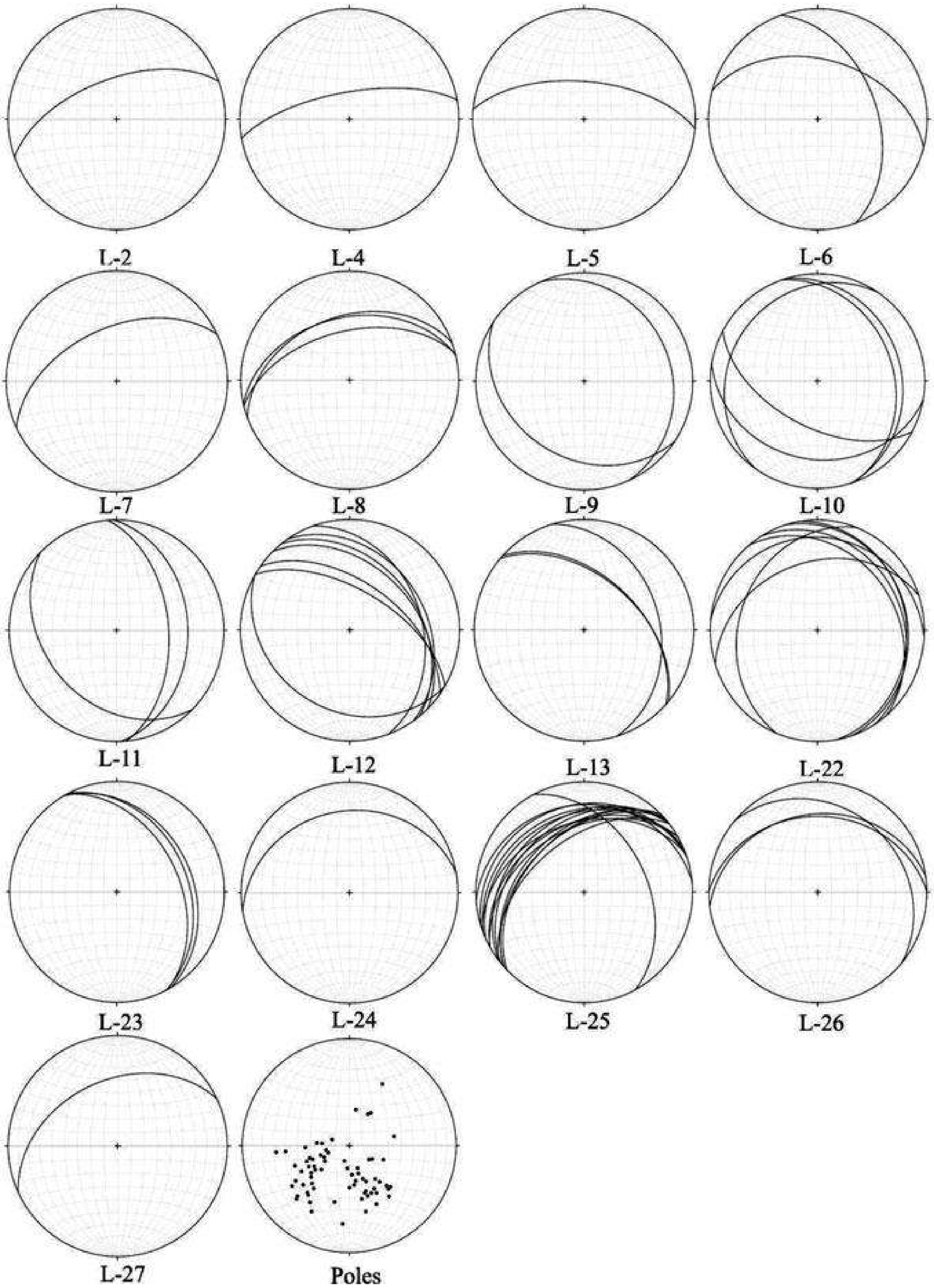

Fig. 5 Location-wise stereo-plots of planar features (joints, schistosity and other foliation planes). Poles of planar data shown

5.1 Folds

Tight, isoclinal and open folds are noted in the field area. Tight isoclinal asymmetric folds are found in light-coloured quartz rich gneissic bands in L-11 to -14 in Darjeeling Formation (Figs. 6 and 7). Open folds are observed in quartz mica schist (L-9) before reaching Mahanadi. Fold axes plunge in variable amount: 8°–38° broadly in three directions: NE, SW and SE.

5.2 Shear Senses

Three shear senses are noted in mica schist and garnet bearing quartz mica schist of Darjeeling Formation: top-to-S, top-to-E and top-to-W. The inclination of the P-planes with respect to the Y-planes are used to deduce the slip sense conclusively, even in absence of any slipped marker layer (e.g., Passchier and Trouw 2005; Mukherjee 2014a, b, 2015). Out of these, only the former shear sense has been reported by the previous authors from this and other Himalayan segments, which is rather common in the collisional mountains as the "fore-shear" (Mukherjee 2007,

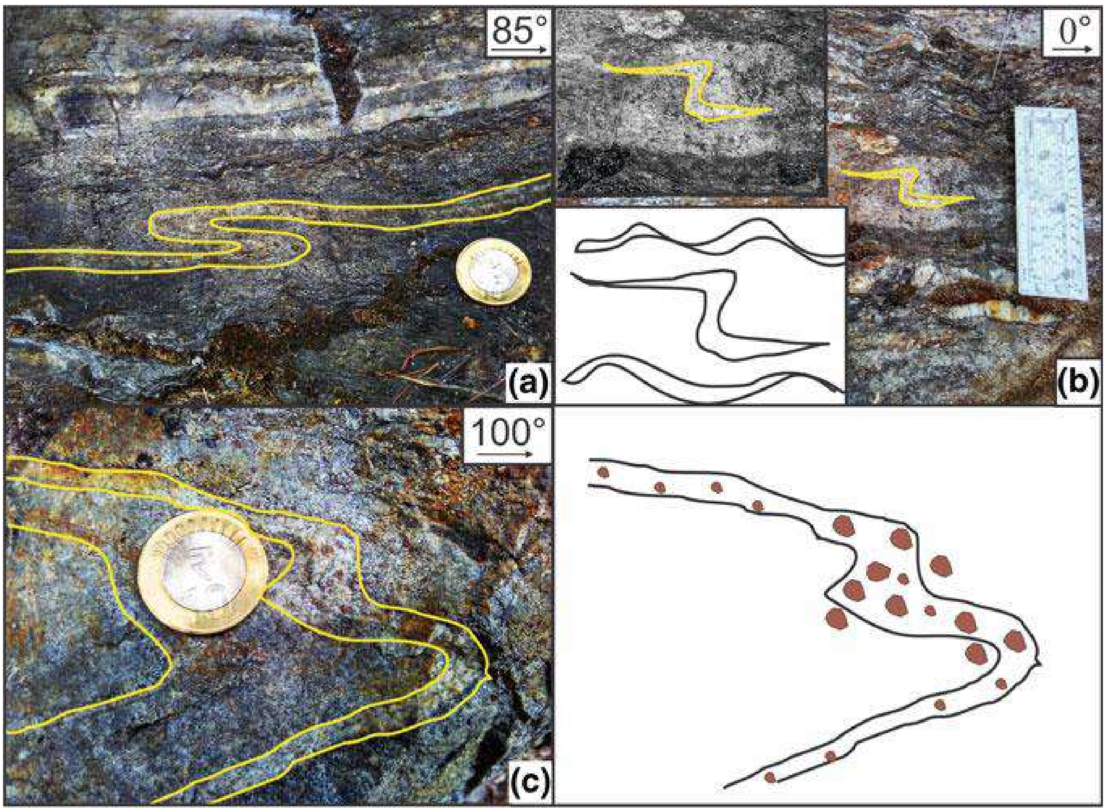

Fig. 6 Folds in gneiss in sub-vertical sections. **a** Folded light quartz rich garnetiferous mica-gneissic and dark micaceous layer in L-13. **b** Tight fold in lighter coloured gneissic layer. A rootless fold is noted at L-15

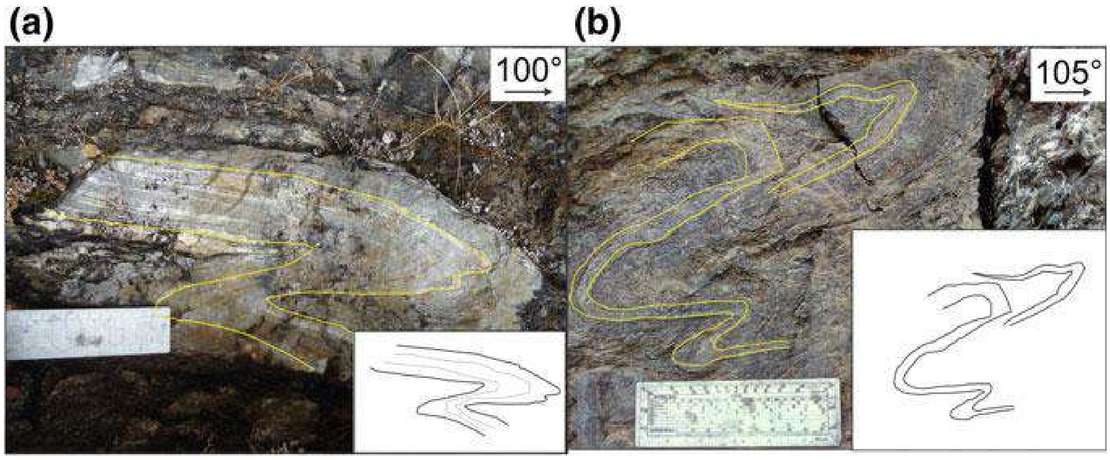

Fig. 7 Tight folds in sub vertical sections of light colouredgarnetiferous quartz mica gneiss. **a** Isoclinal fold in L-10, **b** secondary Z-fold in L-10

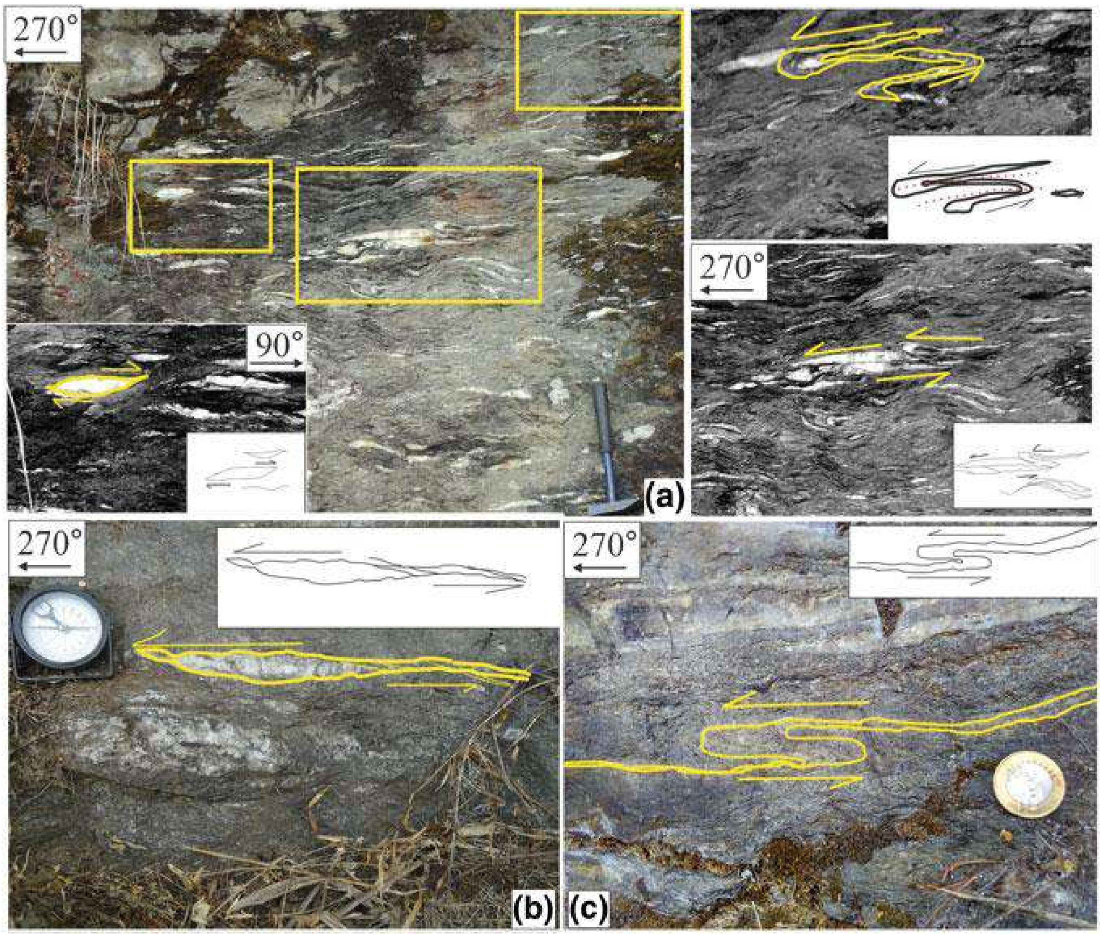

Fig. 8 Top-to-west ductile sheared quartz body within non-foliated micaceous rock in sub-vertical sections. **a** Two shear senses observed in quartz vein within the non-foliated rock at L-10. **b** Sheared quartz vein within the gneissic rock at L-18. Intrafolial folding in garnet-rich light colored band within a non-foliated micaceous rock

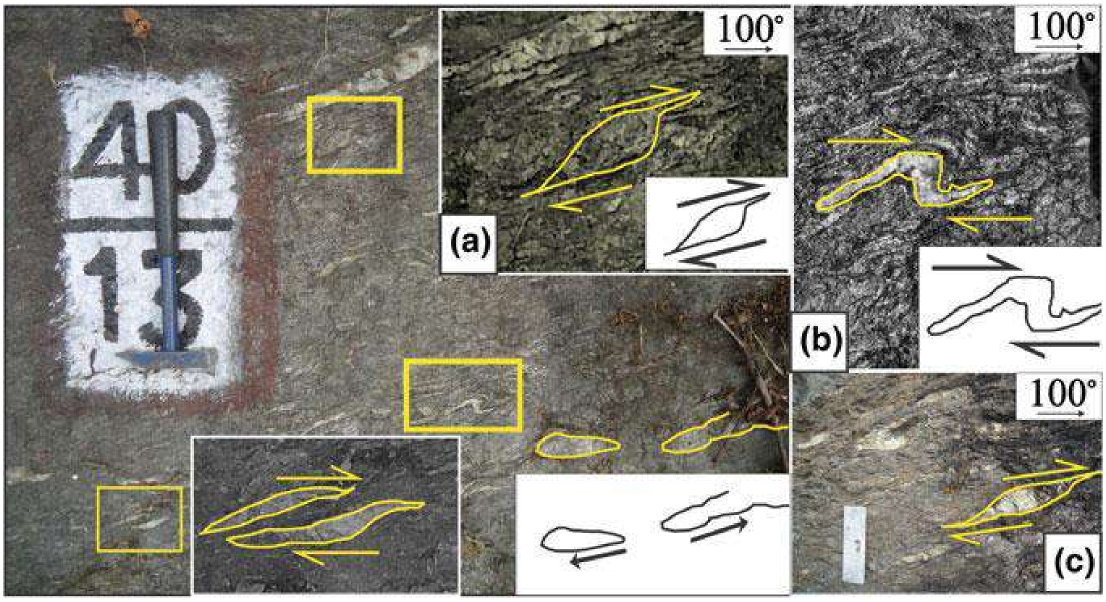

Fig. 9 Top-to-E sheared quartz vein in garnet-bearing mica schist in a sub-vertical section. **a** Lens-shaped quartz vein (L-14). **b** Rootless fold (L-14). **c** Quartz lens (L-10)

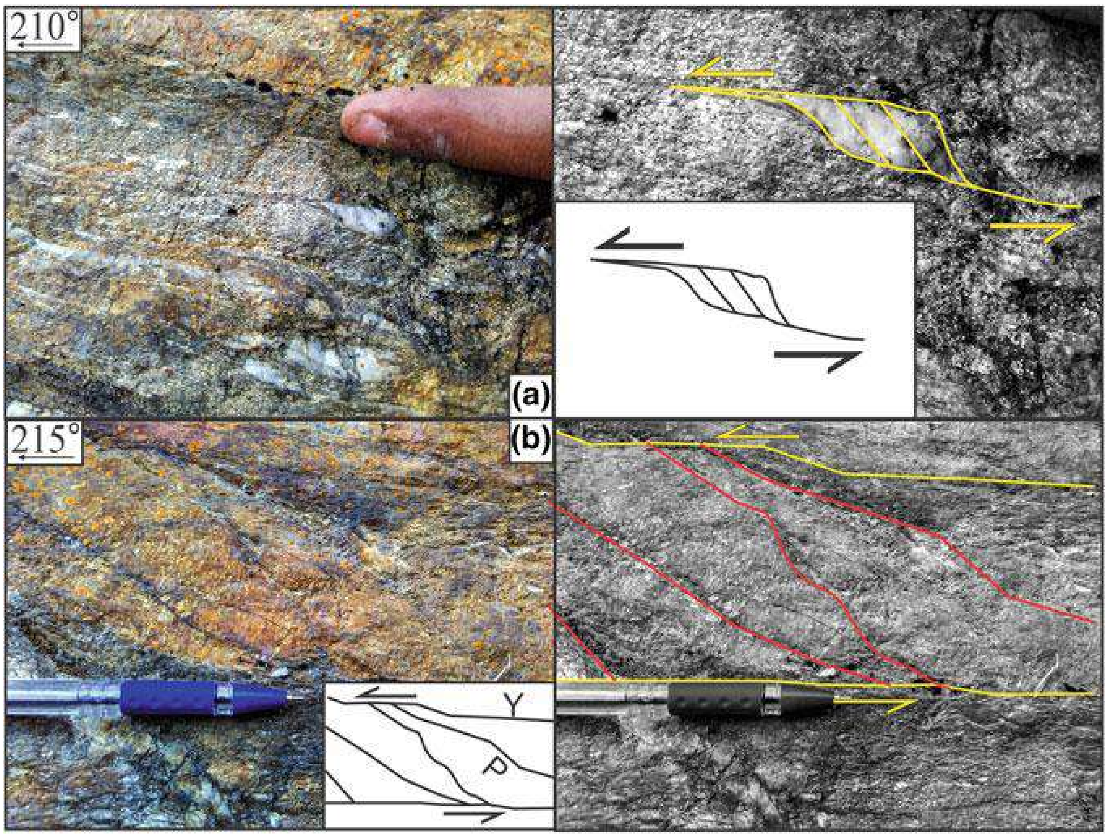

Fig. 10 Top-to-S shear sense observed in sub-vertical sections. **a** Quartz fish at L-6. **b** Brittle Y- and P-planes in low grade schist in L-6

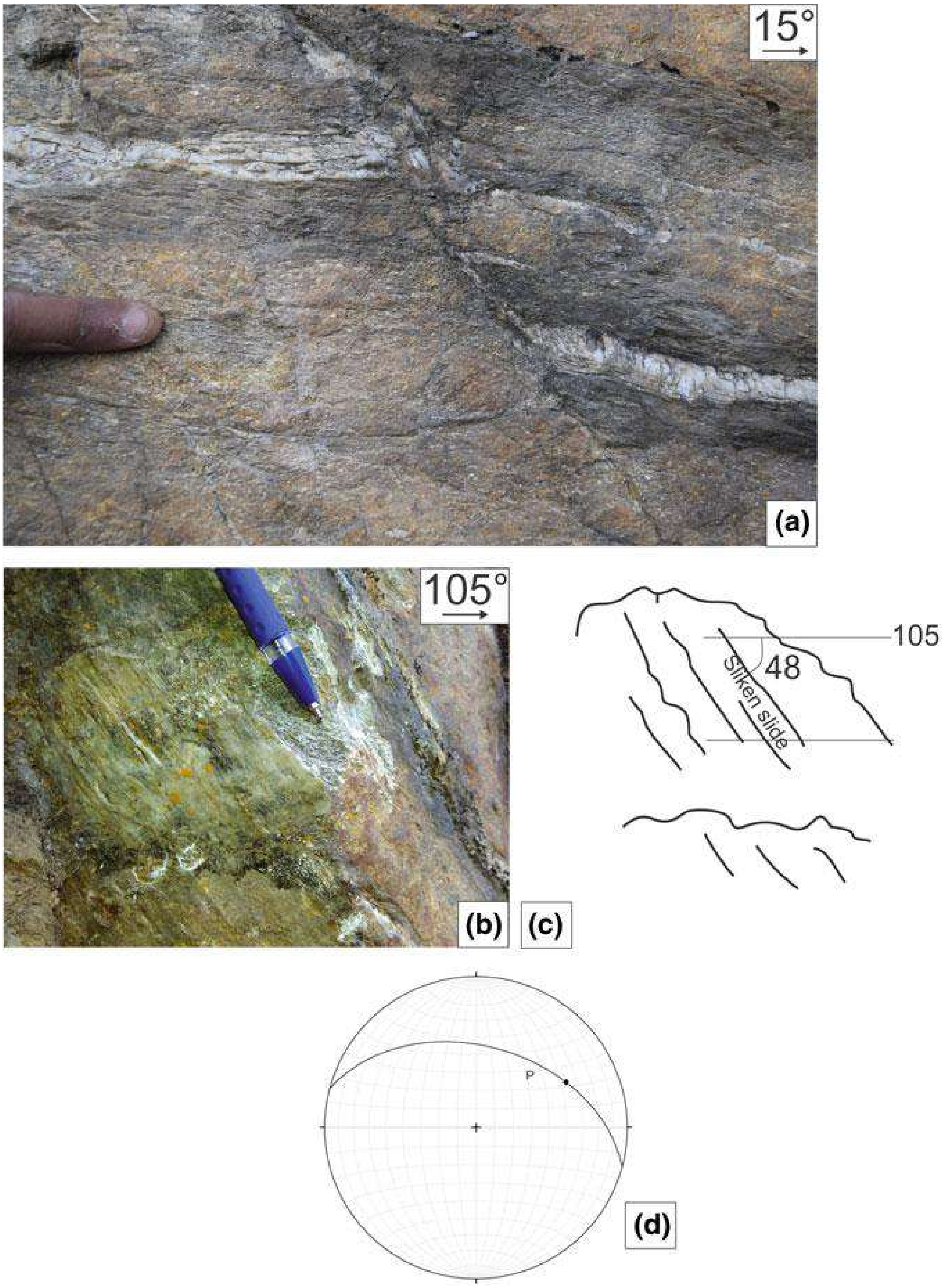

Fig. 11 **a** Small scale normal fault observed in L-6 marked by displacement of quartz vein seen in a sub vertical section, **b** fault plane containing slicken slide within it, **c** sketch of the slicken slide lineation on the fault plane. plunge 34° towards 62°E, **d** stereo-plot of the fault plane and the lineation on it

2012, 2013a, b, c; Mukherjee and Koyi 2010a, b). The rest of the shear senses are the new findings through this work. Intrafolially folded quartz veins show a top-to-W shear around L-10 (Mukherjee et al. 2015; Fig. 8). Top-to-E shear in L-14 is marked by rootless intrafolial folds, lens-shape mineral fish of quartz (e.g., Mukherjee 2011), fracture planes in quartz vein (L-19), around Rohiniroad (Fig. 9). Asymmetric eye/augen-shaped clasts (Fig. 3 and 11a) and brittle Y- and P-planes in L-6 (Fig. 10) characterize the top-to-S shear. Orogen-parallel shear (top-to-E and -W) are also new findings in this work. Mahato et al. (2019) also report the same from the Lesser Himalaya from Garhwal region, Uttarakhand. Orogen parallel deformation is also recently further reported from Mohand area, Siwalik (Dutta et al. submitted).

5.3 Small Scale Normal Faults

In L-6 (~950 m before the Gayabari railway station), a single small-scale NNE dipping normal fault (Fig. 11) was observed within the high-grade phyllitic rock unit marked by the slip of a narrow quartz vein. The vein also shows a small-scale pinch-and-swell geometry.

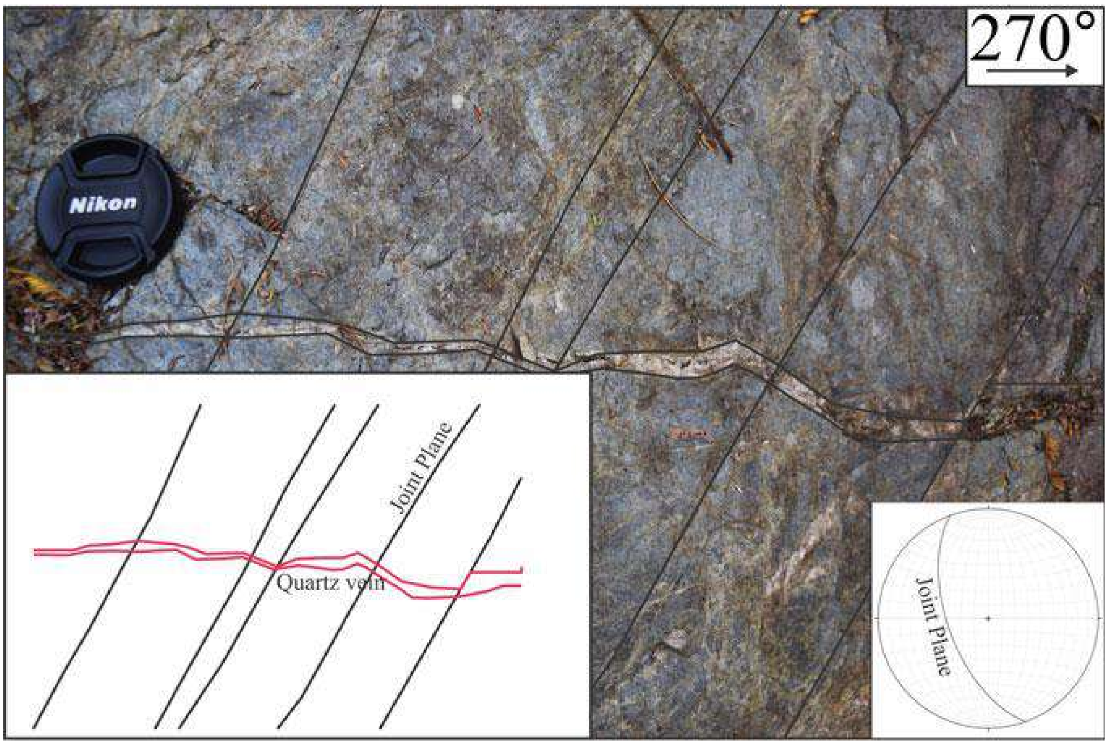

Fig. 12 Joint planes in phyllitic rock cross-cutting quartz vein in L-5, observed in a sub-vertical section

5.4 Foliations and Joints (Fig. 12)

Foliation planes in the Tindharia–Kurseong section dip towards N, NE, SW. In Kurseong–Rohini section, they dip towards E and NW, and in the Kurseong–Pankhabari section towards NW, N and NNE. Two sets of joint planes were seen in phyllite at L-27 (~2.8 km before the location Pankhabari in the Kurseong–Pankhabari road). One set of joint planes dip towards NW.

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