Analysis of lineament swarms in a Precambrian metamorphic rocks in India

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Addressing the geologic significance of lineaments and their correlation with joints/fractures is still unclear. The present study attempts to analyse the lineament swarms developed in a Precambrian metamorphic terrain in India using both unfiltered and filtered techniques. The unfiltered analysis technique shows that the major lineament and fracture trends are oriented along EW and NS directions respectively, thus failing to provide any correlation between them. The application of domain-based filtering techniques identifies a highly predominant fracture-correlated lineaments in mica schist constituting the EW trending shear zone in the area. This correlation is not evident in the areas north and south of the shear zone, where the lineaments are consistently oriented along the foliation planes of the rocks and are designated as 'foliation correlated'. The present analysis indicates that the fracture frequency and the strain history may have played significant roles for the formation of fracture-correlated lineaments in the metamorphic terrain.

1. Introduction

Lineaments are natural, linear surface elements, interpreted directly from satellite imagery and geophysical map and have been called fracture traces, and many other names (Parizek 1976; Garza and Slade 1986; O'leary *et al* 1976) and also used for water resource investigations (Boyer and McQueen 1964; Brown 1994; Lattman and Parizek 1964; Peterson 1980; Mah *et al* 1995; Dhakate *et al* 2007) and structural geologic studies (Blanchet 1957; Henderson 1960; Hodgson 1961; Lattman and Segovia 1961; Caran *et al* 1982; Acharya *et al* 2007; Rahiman and Pettinga 2008; Kazemi *et al* 2009), considering lineaments as the surface expressions of joints/fractures or zone of joint concentration. Practical experiences of many hydrogeologists and petroleum geologists were that suggesting locations for dug wells, tube wells and drill wells in crystalline metamorphic and igneous terrain, based on lineament data, did not always yield a good success rate. Several studies show a significant deviation of lineaments from dominant joint/fractures (Lattman and Matzke 1961; Matzke 1961; Lipfert *et al* 2001; De'gnan and Clark 2002), demanding more investigations to analyse the lineaments in Precambrian metamorphic rocks.

The study area is located in and around Balarampur, Purulia district, West Bengal, India, within 23°02′47″–23°07′41″N latitudes and 86°10′00″–86°19′02″E longitudes (figure 1), which is underlain by jointed/fractured metamorphic rocks providing lineament swarms to carry out critical analysis of lineaments and their correlating

Keywords. Lineament; fracture; remote sensing; hydrology; data analysis.

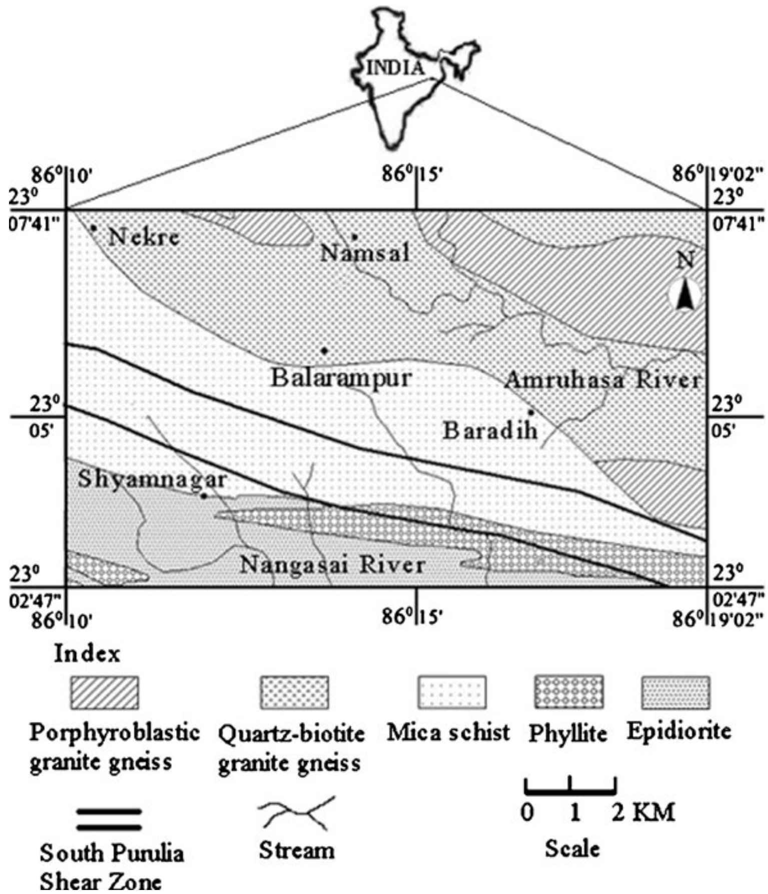

Figure 1. Geological map of the study area in Purulia district, West Bengal, India.

factors. Acharya and Chatterjee (2010) showed a good number of lineaments without any high yielding well-sites in the study area. There exists a few studies investigating lineaments (Acharya *et al* 2007) and subsurface bedrock fractures (Mallik *et al* 1983; Nag 1999) in and around Balarampur. Visual interpretation of lineaments in this area was made from IRS-P6 LISS III standard FCC imageries treating the lineaments literally as straight lines in the horizontal plane in 1:50,000 scale. Only 'geological lineaments' are extracted from the total lineaments in the study area ($\sim$132.9 km^2) by comparing with toposheet-features and excluding the 'non-geological lineaments' after ground truth verification. 'Geological lineaments' and the structural data obtained by field studies have been compared, by taking into account the dominant azimuth sets, in the following three ways:

- unfiltered analysis,
- filtered, domain-based analysis, and
- filtered, discrete-analysis-based analysis techniques to identify fracture-correlated lineaments.

The ongoing electrical resistivity study supplements the results of this paper.

2. Geological setup

The study area is located at the junction of Chhotanagpur Granite Gneissic Complex (CGGC) and the Singhbhum Group of rocks (SG), exposing metamorphic rocks of Proterozoic age (Baidya 1992; Gupta and Basu 2000) (figure 1). At the north the CGGC is a part of the Chhotanagpur Craton consisting varieties of granite gneisses, such as quartz-biotite granite gneiss and porphyroblastic granite gneiss. The SG rocks, exposing at the south belongs to Singhbhum orogenic belt and comprises chiefly of mica schist and phyllite. NW–SE foliations are well developed both in the CGGC and in the metasedimentaries of Singhbhum Group (Geological quadrangle map 73-I 1948) due to tectonic stress along NS direction. The foliations in the area statistically dip high (>57°) towards north. The metasediments of SG are interlayered with basic bodies, locally described as epidiorite sills, which may have a strong genetic connection with the Dalma Volcanics (Geological quadrangle map 73-I 1948). Presence of more than one generation of minor folds indicates imprints of polyphase deformation of the rocks. Geometry of the first generation fold is not preserved due to absence of exposures of competent horizons. Evidences of shear forces acted along some EW trending nearly vertical weak planes during the third tectonic period (Geological quadrangle map, 73-I, 1948) are noticeable in the region of southern Purulia shear zone. CGGC was thrusted towards south over SG (Katti *et al* 2010). In this area such structural elements are mainly represented by some shear-joints and fractures in the granitic rocks, pegmatites, quartz veins and metasediments. These shear joints, fractures and faults strike EW, in general, with 60^o to nearly vertical dips (Geological quadrangle map 73-I 1948). Two prominent shear zones: (a) North Purulia Shear Zone (NPSZ) and (b) South Purulia Shear Zone (SPSZ) (marked in figure 1) are known to occur in the Purulia district. The SPSZ trends almost EW and passes through the south of Balarampur. This shear zone shows phosphate and other mineralisation. Figure 2 demonstrates the field photograph of highly foliated gneissic rocks from CGGC indicating prominent weathering along foliations. Figure 3 exhibits the highly fractured phyllite.

Figure 2. Grooves and furrows developed in the highly foliated granite gneiss due to differential weathering along foliation planes.

3. Methodology

The following are the details of the methodology adopted in the present study.

3.1 *Laboratory studies*

Lithological (figure 1) and lineament (figure 4) thematic maps have been created from the Geocoded 73-I/4, 73-I/8 (1) and 73-I/8 (2) satellite imageries of IRS-P6 standard (band 2 3 4) false colour composite (FCC) on the base map, prepared using the Survey of India toposheets numbered 73-I/4 and 73-I/8 at 1:50,000 scale. Lineament map has been prepared by detecting and tracing lineaments

Figure 3. Well developed fractures in phyllite.

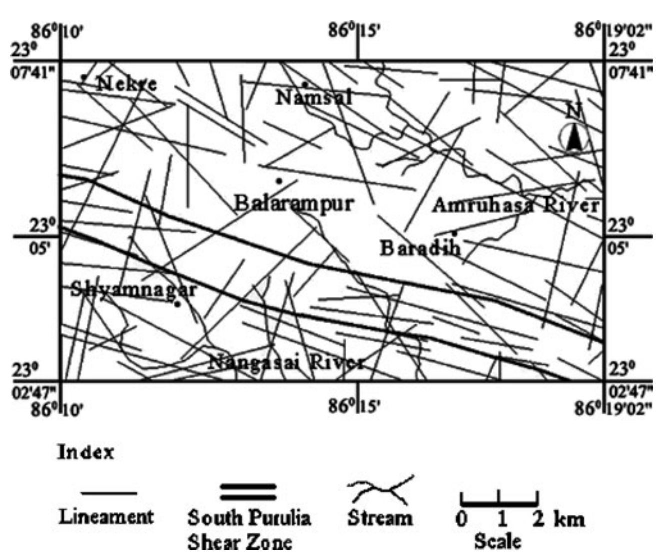

Figure 4. Map of the area showing the geologic lineaments.

from satellite imageries on the basis of textural, soil tonal, vegetation, topographic and drainage linearities (Lillesand 1989; Drury 1990; Gupta 1991) by visual interpretation. The non-structural and 'false' lineaments have been eliminated after comparing lineament map with the corresponding toposheets (73-I/4, 73-I/8) and field verification leaving the 'geologic lineaments'. The lithological map (figure 1) has been prepared by visual interpretation of the satellite imageries and field investigation. The structural data featuring joints/fractures, foliations and lineament orientations have been analysed very critically. The lineaments for fracture-correlation have been categorized as in Moore *et al* (2002). These are:

- unfiltered lineament analysis technique which involves comparison of all lineament data with all fracture data of the entire area.
- filtered, domain-based fracture-correlated lineaments which has been determined by defining fracture families for each grid. The study area has been divided into 15 grid-cells, each cell with dimension of 3×3 km, containing three or more sample points.
- filtered, discrete-analysis-based fracture-correlated lineaments that has been determined by defining structural data for each grid. Square-cell sampling grids have been developed similarly to that of the second technique. This technique examined lineaments by comparing their trends in a dataset with the strike of steeply dipping planar structural features within the same grid. Georient software has been used for quantitative and statistical analyses on lineaments, fractures and foliations. Since the measurements have been taken between 0° and 180° and the circular distributions have been plotted on unit circles with 10° class intervals, the 18 classes before plotting have been duplicated.

3.2 *Field studies*

The field studies were made for ground-truth investigations of photo-lineament location, geometry, continuity and reasons for the abrupt termination, lithology and fracture and other structural features. The field study shows that fracture trends, anomalous topography, contact of lithounits, natural alignment of trees, rivers and streams are the representatives of lineaments on the ground. Some lineaments have, however, not been traceable on the real ground. Foliation is prominent in quartz-biotite granite gneiss, porphyroblastic granite gneiss, epidiorites, mica schist and phyllite. A shear zone underlain by mica schist has a width of about 1.5 km and passes through the south of Balarampur along EW direction. Rock exposures displaying 3-D visualisation of the fracture and other structural data has always been selected for data recording. Measurements have been made of:

- attitude (strike and dip) of joint/fracture sets,
- frequency of fracture planes (number of planes in a meter across a normal line),
- length of the fractures,
- attitude (strike and dip) of the foliation and the schistosity of the rocks, and
- aperture of the fractures.

Foliations dip steeply (ranging from 57° to 90°) northward. For statistical significance, the attitude of a set of fractures has been taken as the average of three measurements from different points of an outcrop (Mallik *et al* 1983). In this study only the orientation and fracture frequency of the fractures have been taken for analysis.

4. Data analysis

The joint/fracture planes dipping 45° or more measured in the field have only been considered for the analysis since straight line lineaments are formed by steeply dipping planes (De'gnan and Clark 2002). In our analysis initially the unfiltered lineament analysis (Moore *et al* 2002) was done for comparison of all the lineament and fracture data of the whole area. Table 1 shows the frequency percentage of all lineament and fracture trends in the

Table 1. *Frequency percentage of lineament and fracture trends.*

Trend interval	Percentage of lineament frequency	Percentage of fracture frequency
0–10	3	8
10.1–20	8	11
20.1–30	4	5
30.1–40	3	5
40.1–50	3	5
50.1–60	5	5
60.1–70	3	5
70.1–80	4	3
80.1–90	4	4
90.1–100	17	6
100.1–110	11	3
110.1–120	10	6
120.1–130	10	4
130.1–140	4	5
140.1–150	3	9
150.1–160	4	2
160.1–170	3	8
170.1–180	3	5

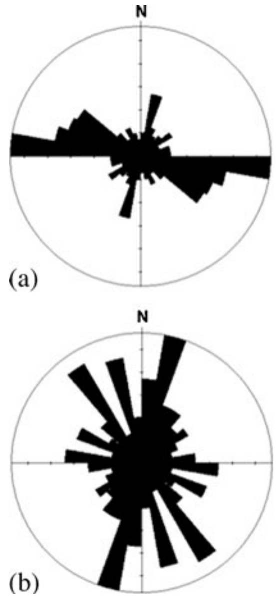

Figure 5. Azimuth-frequency (rose) diagrams of (**a**) lineament orientations and (**b**) fracture orientations in the study area.

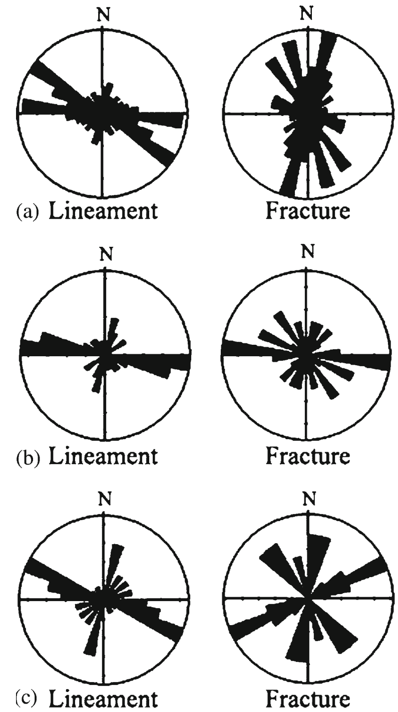

Figure 7. Lineament rosettes and fracture rosettes in (**a**) the northern domain (D1), (**b**) the shear zone (D2), and (**c**) the southern domain (D3).

study area. The unfiltered lineament analysis for all lineaments and fractures, as shown in rose diagrams (figure 5), clearly demonstrated dominant lineament geometry along EW (43%) (figure 5a) while the fractures are distributed between 20° and 40° (32%) (figure 5b), revealing a significant discordance between lineament and fracture trend in the area. Broadly, these findings contradict the main idea inherent in performing any lineament analysis that lineament trends represent fracture zones (Mabee *et al* 1994).

The total area under study has been classified into 15 square grid cells each having dimension 3×3 km to perform the filtered, domain-based fracture-correlated lineament analysis (Moore *et al* 2002). Representative lineament and fracture families of each cell have been plotted as frequency-azimuth (rose) diagrams using the Georient Software (figure 6) showing clear discrepancy between

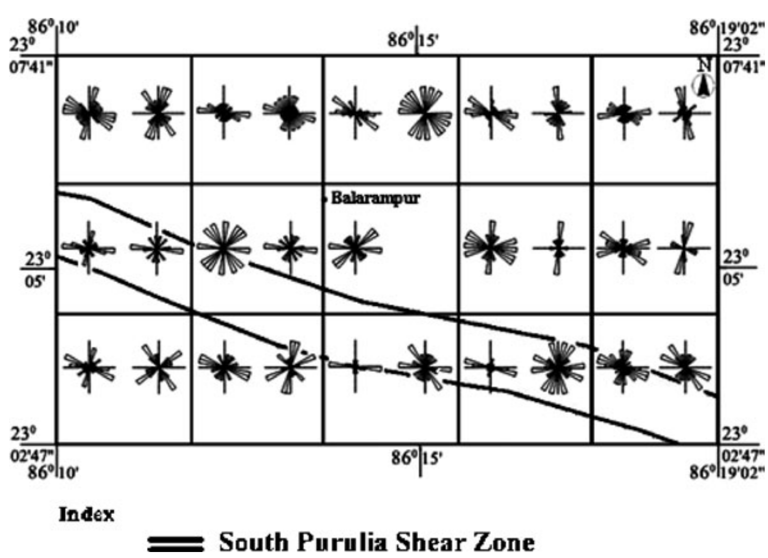

Figure 6. Map showing spatial distribution of lineament rosettes and fracture rosettes in grid cells (3×3 km in size). In each grid cell, lineament rosette is shown in left-hand side and fracture rosette in right-hand side.

Table 2. *Comparison of major lineament and fracture trends in the three domains.*

Major trends	North of shear zone (D1)	Within shear zone (D2)	South of shear zone (D3)
Lineament trends	E–W, NW–SE	E–W	WNW–ESE
Fracture trends	N–S	E–W	NW–SE

the prominent lineament direction(s) and prominent fracture direction(s) of each cell, except those within the SPSZ.

As the study area occurs at the junction of the Chhotanagpur and Singhbhum cratons comprising a shear zone in between, the grid cells in the northern part of the shear zone have been fused to form a single domain. Similarly the grid cells contained in the shear zone and those in the southern part of the shear zone have been clubbed into two separate domains. Thus the area has been divided into three domains:

- region occurring north of shear zone (D1),
- the region within the shear zone (D2), and
- the region south of the shear zone (D3).

The lineament and fracture trends of each domain have been presented separately (figure 7) and listed in table 2. In D1, the lineaments trend chiefly along EW and NW–SE directions and the dominant fractures (37%) trend along NS direction, indicating fracture non-correlated lineaments (figure 7a). The domain, D2, shows both lineaments (46%) and fractures (37%) trending along the EW direction (figure 7b), indicating a strong agreement of the lineament and fracture trends and hence the lineaments can be designated as fracture-correlated. In D3, the dominant lineament and fracture trends are respectively along WNW–ESE/N–S, the former being more prominent, and NE–SW (38%)/NS (30%) directions (figure 7c), clearly indicating dominant lineaments to be fracture non-correlated and NS trending intermediate lineaments to be fracture-correlated. The analysis shows fracture non-correlated lineaments in D1 and D3. Comparison of figures 5 and 7 will immediately indicate the use of filtering technique for analysis of correlation between lineaments and fractures.

Mainly four lithology types are exposed in the area, i.e., granite gneiss, mica schist, phyllite and epidiorite. The lineament and fracture trend data as recorded from these lithologies have been classified in table 3, and their rose diagrams in figure 8 indicate the effects of lithology on them. The granite gneiss, traversed by NW–SE trending lineaments, has developed fractures largely trending along NNE–SSW directions (figure 8a). The mica schist has EW trending lineament with fractures orienting along EW and NW–SE directions (figure 8b). In phyllite, the dominant lineament trends is EW, while the fracture trends are given by NNE–SSW and NW–SE directions (figure 8c). The epidiorites have the lineaments along NNE–SSW and ESE–WNW directions and the fractures along EW and NS directions (figure 8d). Comparison of lineament with lithology shows different lineament and fracture trends except between mica schists and phyllites. Similar trends in lineaments and fractures in mica schists and phyllites may be due to ductile nature of rocks.

Further, in order to study the effect of rock type on the fracture and lineament correlation, the lineaments and fractures of mica schist have sorted out which occur within and outside the shear zone. The mica schist has EW directions for both the fracture and lineament in the shear zone, as shown in figure 9(a) and has NW–SE and WNW–ESE directions for the lineament and NS directions for the fractures outside shear zone, as represented in

Table 3. *Comparison of major lineament and fracture trends in the lithology types.*

Lithology	Major lineament trends	Major fracture trends
Granite gneiss	NW–SE	NNE–SSW
Mica schist	E–W	E–W, NW–SE
Phyllite	E–W	NNE–SSW, NW–SE
Epidiorite	NNE–SSW, ESE–WNW	E–W, N–S

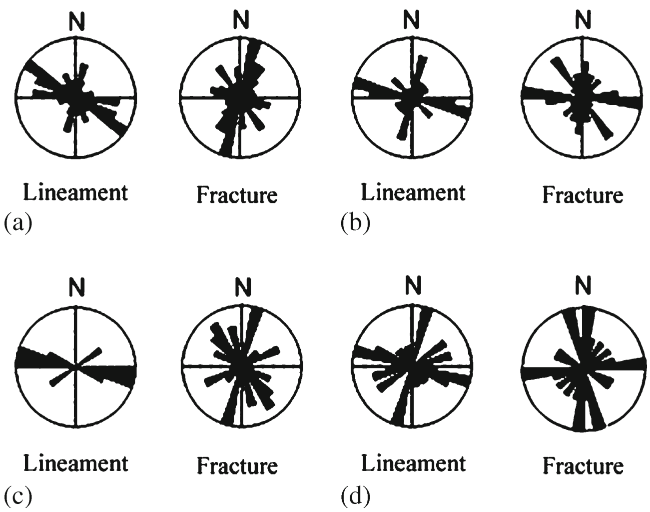

Figure 8. Azimuth-frequency (rose) diagrams showing lineament orientation and fracture orientation in the lithology types. (**a**) Granite gneiss, (**b**) mica schist, (**c**) phyllite, and (**d**) epidiorite.

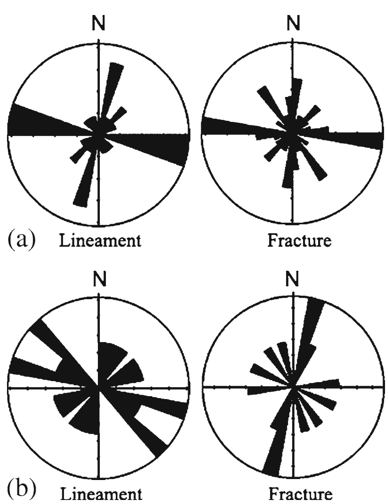

Figure 9. Azimuth-frequency rosettes showing lineament orientation and fracture orientation in mica schist: (**a**) within the shear zone and (**b**) outside the shear zone.

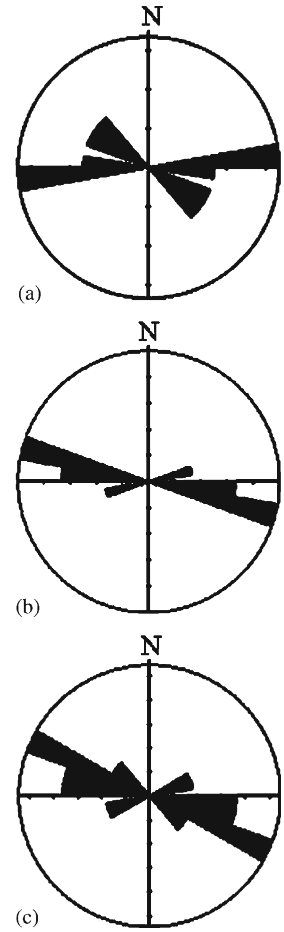

Figure 10. Azimuth-frequency (rose) diagrams of foliation orientation in (**a**) the northern domain (D1), (**b**) the shear zone domain (D2), and (**c**) the southern domain (D3).

figure 9(b). This shows that mica schist produces fracture-correlated lineaments in the shear zone but outside the shear zone their correlation is not significant indicating that the correlation of lineament is also dependent on other structures than fractures.

Foliation plane, which is commonly developed as a result of tectonic strain is one of the important structural features of metamorphic rocks, perhaps need consideration in the analysis of lineaments for fracture correlations. Azimuth-frequency (rose) diagrams of representative foliation families of each domain (i.e., D1, D2 and D3) have been constructed (figure 10) and compared with trends of lineaments of the corresponding domain to perform the filtered, discrete-analysis-based technique, indicating foliation-parallel lineaments trending along EW/NW–SE directions in D1 (figure 10a) and WNW–ESE in D3 (figure 10c). In D1, granite gneiss displays prominent alteration zones along the foliation planes (figure 2), developing lineaments paralleling foliations. The mica schist, phyllite and epidiorite in D3 show prominent structural discontinuities like schistosity and foliation, developing lineaments along foliations. Thus, metamorphic rocks outside the shear zone reveal a significant effect of foliations on the lineament orientations. As there has been no evidence of fault zones/fractures parallel to these directions, the lineaments may be designated as 'foliation-correlated' which is strongly controlled by the tectonic strain history of the region. In D2, EW trending foliations (figure 10b) perhaps combine with dominant fractures to produce lineaments with high fracture correlation.

Frequency of joints/fractures, measured as number of joint planes of a particular set crossed in a perpendicular traverse of 1 m, ranges from 1 to 34 per meter in the study area. More closely spaced fractures with higher frequency may represent more potentially transmissive bedrocks (Mabee and Hardcastle 1997). Though fracture frequency database is not very large, the scatter-plots between fracture strike and fracture frequency, constructed for the each domain, D1, D2 and D3, using Statistica software (figure 11) show a very interesting feature. The fracture set, striking EW, exhibits higher frequency (>15/m) in the domain of shear zone (D2) (figure 11b), paralleling the trend of fracture-correlated lineaments. In the domains D1 and D3, fractures show lower frequencies (<15/m) (figure 11a and c), except the NS trending fractures in D3 which is typified by higher fracture-frequency (>15/m), perhaps corresponding the NS trending intermediate fracture-correlated lineaments in D3.

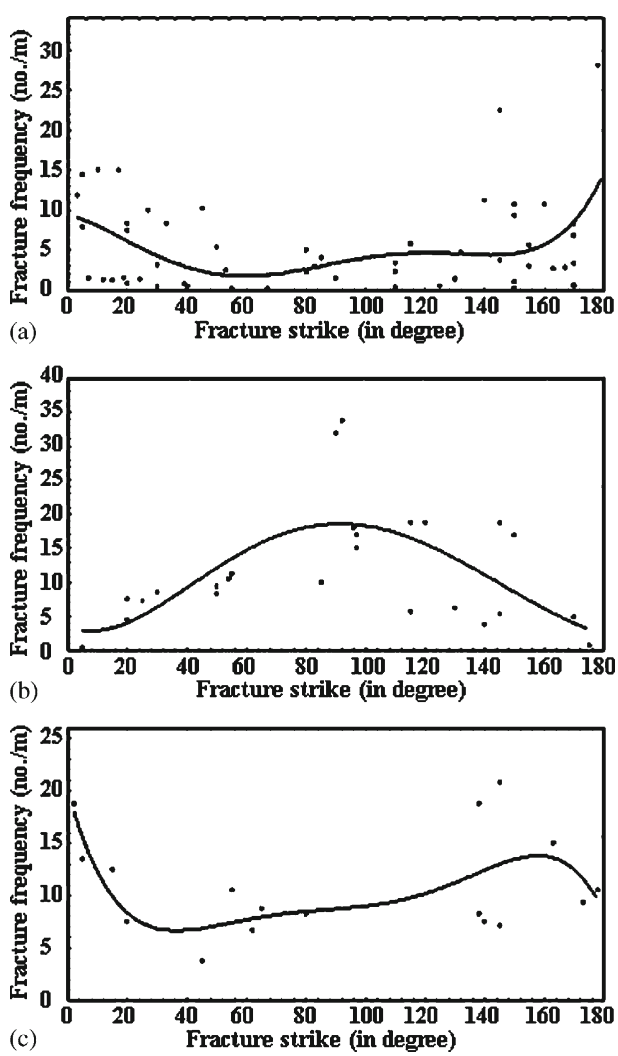

Figure 11. Graphs illustrating the relationship between fracture frequency and fracture strike. (**a**) Northern domain (D1), (**b**) shear zone domain (D2), and (**c**) southern domain (D3).

5. Discussion and conclusions

The lineament swarms derived from remotely sensed imageries over a Precambrian metamorphic terrain at the CGGC–SG region have been checked for ground truth verification followed by recording of outcrop-scale fracture and other data. Unfiltered lineament analysis technique fails to identify overall correlation between lineaments and fractures in the study area. Using filtered techniques of analysis, it is possible to locate the areas where lineament and fracture domains of similar trend overlap. The filtered, domain-based fracture analysis reveals the occurrence of fracture-correlated lineaments in the shear zone (D2). The shear zone comprising chiefly mica schist has EW trending fracture and lineament constituting respectively 37% and 46%. The mica schist has also steeply dipping schistosity planes striking along EW directions, like that of fracture planes. The lineaments are characteristically longer in the shear zone than in the other areas.

In northern domain (D1), granite gneiss clearly exhibits majority of the lineaments oriented along foliations rather than along the fractures with low fracture-frequency (<15/m). This may be attributed to the enhanced weathering of the rocks along the foliation planes. Therefore, the more intense and pervasive foliation planes are perhaps favoured to produce lineaments in metamorphic rocks and may be designated as 'foliation-correlated' lineaments. The shear zone (D2), comprising chiefly mica schist, shows strong concordance between trends of lineaments and fractures, with high fracture-frequencies (>15/m) and the lineaments are assigned to be 'fracture-correlated'. The mica schist has steeply dipping schistosity planes striking along EW directions, paralleling the shear zone trend. The transport and distribution of fluids, strongly controlled by the shear zone, may facilitate to develop 'fracture-correlated' lineaments. In southern domain (D3), majority of the lineaments are fracture non-correlated, oriented along foliations and, therefore, assigned as foliation-correlated. Intermediate fracture-correlated lineaments are concordant to the fractures characterized by high (>15/m) fracture-frequencies.

Weathering and kaolinization as a result of limited movement of groundwater along foliations, common in gneisses, may raise preferential moisture content along foliations (Ross and Frohlich 1993), forming foliation-correlated lineaments. Brecciated rocks adjacent to the shear zones, as well as the shear zones themselves, can be hydraulically conductive inducing preferential groundwater movement as supported by several researchers (Beamish 1995; Seaton and Burbey

2000, 2005; Harinarayana *et al* 2006; Choudhary and Kunar 2007; Rugh and Burbey 2008;) and form lineaments along fractures. High fracture-frequency means closely spaced fractures. Enhanced permeability associated with the fracture set, showing high fracture-frequency, characterizes differential moisture content along the fractures favouring development of fracture-correlated lineaments. This is rightly pointed out by several researchers (Braathen 1999; Henriksen and Braathen 2006). More closely the fractures are placed, the more is the tendency of groundwater to flow along those closely spaced fractures, causing potential weathering along the flow path, facilitating to produce fracture-correlated lineaments.

Fracture non-correlated lineaments may limit its use in groundwater supply and other applications. Results show that the fracture-correlated lineaments traversing the shear zone may perhaps be further enhanced by foliation and high fracture frequency of the rocks. The lineaments exhibited in the areas off the shear zone geographically correlate with foliation planes developed by the regional stress field of the rocks, thus qualifying the lineaments as 'foliation-correlated'. The present analysis indicates that the fracture frequency and tectonic strain history of the region may have played significant roles in the formation of lineaments in the older metamorphic rocks.

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