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Hydraulic Significance of Fracture Correlated Lineaments in Precambrian Rocks in Purulia District, West Bengal

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Abstract: Filter analysis of lineaments in Precambrian metamorphic rocks was used to delineate fracture-correlated lineaments and hydraulically significant fractures. The unfiltered analysis technique fails to show correlation between major lineaments and fractures. Domain-based and discrete filtering techniques successfully identify fracture-correlated lineaments within the brittle-ductile shear zone in conjunction with fractures characterized by high fracture frequencies (>10/m). The locales of hydraulically significant fractures can thus be assessed if the geological controls governing the spatial distribution of fracture frequencies are computed using structural domain approach. The concurrence of fracture-correlated lineaments and hydraulically significant fractures within the brittle-ductile shear zone is evident.

Keywords: Lineament, Fracture, Shear-zone, Fracture-frequency, Hydraulically significant fracture, West Bengal.

INTRODUCTION

Lineaments are natural, linear surface elements, interpreted directly from satellite imagery and have been called fracture traces, and many other names (Garza and Slade, 1986; Parizek, 1976). These lineaments are used for water resource investigations (Boyer and McQueen, 1964; Brown 1994; Dhakate et al. 2008; Lattman and Parizek, 1964; Mah et al. 1995; Peterson, 1980) and in structural geologic studies (Acharya et al. 2007; Blanchet, 1957; Caran et al. 1982; Henderson, 1960; Hodgson, 1961; Lattman and Segovia, 1961; Rahiman and Pettinga, 2008; Kazemi et al. 2009). Practical experiences of many hydrogeologists (Gleeson and Novakowaski, 2006; 2009; Magowe and Carr, 1999; Orsi, 2004; Owen et al. 2002; Sander et al. 1997) 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 (Acharya and Mallik, 2012; De'gnan and Clark, 2002; Lattman and Matzke, 1961; Lipfert et al. 2001; Matzke, 1961), demanding more investigations of the fracture-correlated lineaments and hydraulically significant fractures in Precambrian metamorphic rocks.

The present study area is located in and around Balarampur, Purulia district, West Bengal, India, within 23°02'47" to 23°07'41" North latitudes and 86°10'00" to 86°19'02" East longitudes (Fig.1), which is semi-arid and the most drought-prone, underlain by jointed/fractured metamorphic rocks providing lineament swarms. The bedrocks are the Chhotanagpur Gneissic Complex, consisting varieties of granite gneisses (i.e. quartz-biotite granite gneiss and porphyroblastic granite gneiss) and the Singhbhum Group of rocks, comprising chiefly of mica schist and phyllite of Proterozoic age (Baidya, 1992; Gupta and Basu, 2000). The steeply dipping NW-SE trending foliations are consistently well developed throughout the study area (Geological quadrangle map 73 I, 1948). The South Purulia Shear Zone (SPSZ), trending almost E-W, developed along the northern margin of the Singhbhum Group of rocks with the Chhotanagpur Gneissic Complex passing through the south of Balarampur, exhibits features indicative of a brittle-ductile deformational regime (Bhattacharya, 1989; Dasgupta, 2004). There exist a few studies investigating lineaments and subsurface bedrock fractures in and around Balarampur showing discordance between the trends of dominant lineaments and fractures (Mallik et al. 1983; Nag, 1999; Acharya et al. 2007; Acharya and Chatterjee, 2010; Acharya and Mallik, 2011). The main objective of this study was to analyze the fracture-correlated lineaments and its relation to the hydraulically significant fractures using lineament and bedrock fracture data analysis.

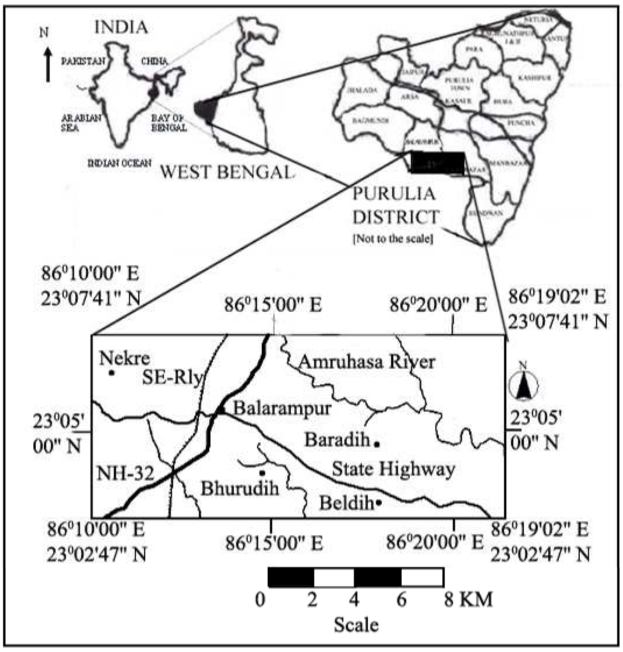

Fig.1. Map of the study area in Purulia district, West Bengal.

METHODOLOGY

To carry out critical analysis to delineate fracture-correlated lineaments in a typical hard rock environment, lithological (Fig. 2) and lineament (Fig. 3) thematic maps have been created from visual interpretation of the Geocoded 73 I/4 and 73 I/8 satellite imageries of IRS-P6 LISS III standard false colour composite (FCC) and comparing with the toposheets and field investigation. An E-W trending tectonic zone is prominent in the imageries and has been marked in the lithological map.

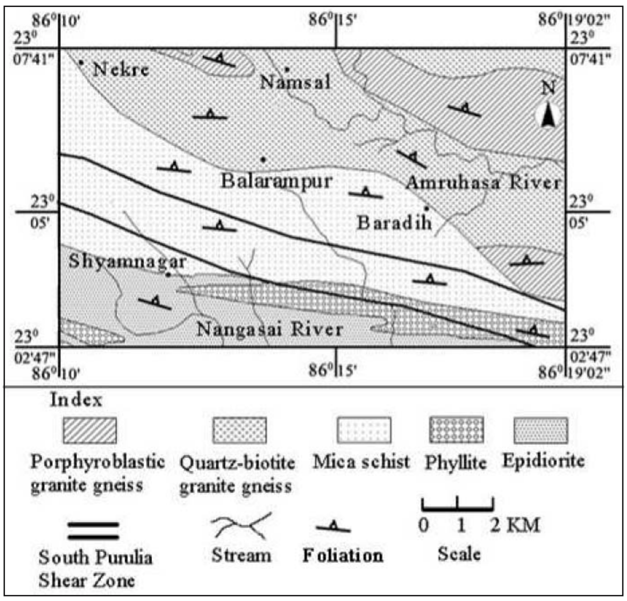

Fig.2. Geological map of the study area.

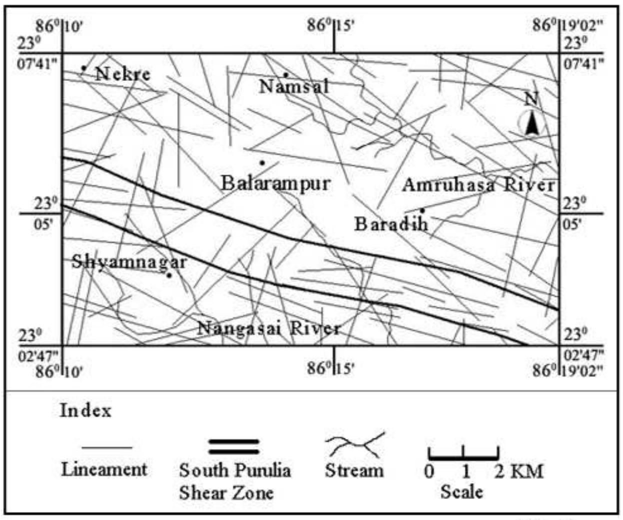

Fig.3. Map of the area showing the geologic lineaments.

The lineaments, structural data featuring joints/fractures, foliations of the rocks have been analyzed comparing the rose diagrams using Georient software and frequencies of fractures have been documented in 2D scatter plots using Statistica software. The lineament analysis for fracture-correlation has been categorized (Moore et al. 2002; Acharya and Mallik, 2012) as:

(1) unfiltered lineament analysis technique which involves comparison of all lineament data with all fracture data,

(2) filtered, domain-based fracture-correlated lineaments, determined comparing with fracture families for each grid. The study area has been divided into 15 grid-cells, each with dimension of 3 km x 3 km, containing three or more sample points,

(3) filtered, discrete-analysis-based fracture-correlated lineaments, determined comparing with structural data for each grid similar to that of the second technique.

The joint/fracture planes dipping 45° or more measured in the field have only been considered for the analysis since straight line lineaments are assumed to be formed by steeply dipping planes (De'gnan and Clark, 2002).

UNFILTERED LINEAMENT ANALYSIS

The unfiltered lineament analysis for all lineaments and fractures, as shown in rose diagrams (Fig.4), clearly demonstrated dominant lineament geometry along E-W (Fig. 4a) while, the fractures are distributed between 20° and 40° (Fig. 4b), revealing a significant discordance between lineament and fracture trend in the area.

FILTERED LINEAMENT ANALYSIS

The total study area has been classified into 15 square

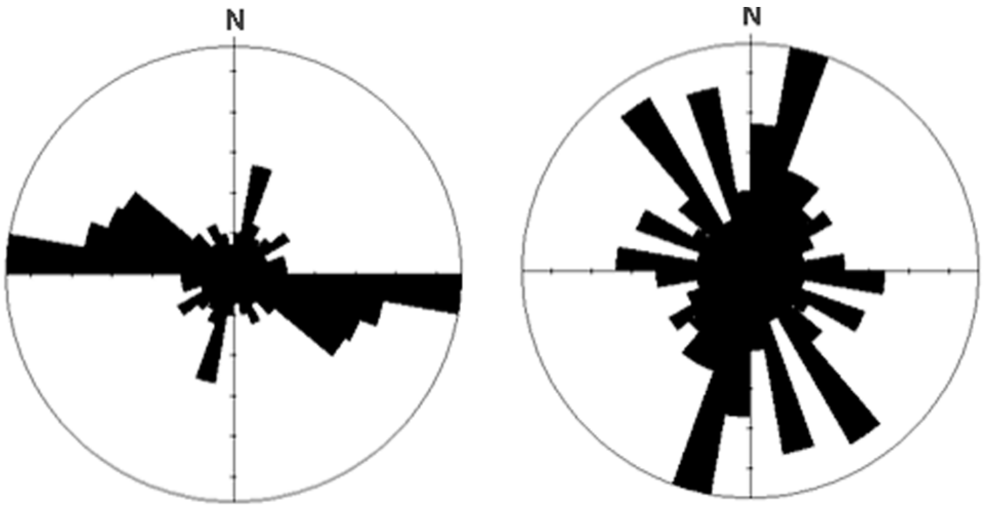

Fig.4. Azimuth-frequency (rose) diagrams of **(a)** lineament orientations and **(b)** fracture orientations in the study area showing an overall mismatch of dominant trends between lineaments and fractures.

grid cells to perform the filtered, domain-based fracture-correlated lineament analysis. Representative lineament and fracture families of each cell, plotted in frequency-azimuth (rose) diagrams (Fig. 5), show a clear discrepancy between the prominent lineament and fracture direction(s) of each cell, except those within the SPSZ.

Domain-based Filtering

As the study area occurs at the junction of the gneissic (i.e. quartz-biotite granite gneiss and porphyroblastic granite gneiss) and the metapelitic (i.e. mica schist and phyllite) rocks comprising a brittle-ductile shear zone (SPSZ) 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 3 domains: (1) region occurring north of shear zone (D1), (2) the region within the shear zone (D2) and (3) the region south of the shear zone (D3). The lineament and fracture trends of each domain have been presented separately (Fig. 6). In D1, the lineaments trend chiefly along E-W and NW-SE directions and the dominant fractures (37%) trend along N-S direction, indicating fracture non-correlated lineaments (Fig. 6a). The domain, D2, shows both lineaments (46%) and fractures (37%) trending along the E-W direction (Fig. 6b), 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%) / N-S (30%) directions (Fig. 6c), clearly indicating dominant lineaments to be fracture non-correlated and N-S trending intermediate lineaments to be fracture-correlated. The analysis shows fracture non-correlated lineaments in D1 and D3.

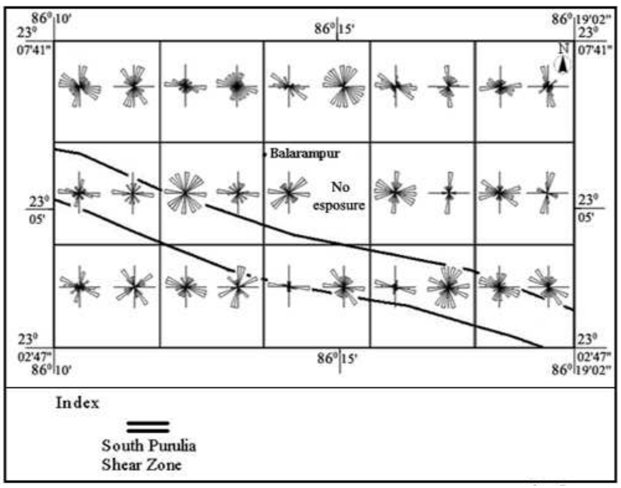

Fig.5. Map showing spatial distribution of lineament rosettes and fracture rosettes in grid cells (3 km x 3 km in size). In each grid cell, lineament rosette is shown in left-hand side and fracture rosette in right-hand side. Major trends of lineaments and fractures are concordant in certain grid cells and discordant in other grid cells.

The mica schist exhibits E-W direction for both the fractures and lineaments in the shear zone (D2) (Fig.7a) and NW-SE / WNW-ESE directions for the lineaments and N-S directions for the fractures outside shear zone (D1 and D3) (Fig.7b). This shows shear zone overprinting the lithological effect for development of fracture-correlated lineaments.

Discrete-analysis-based Filtering

Foliation planes, which are commonly developed and

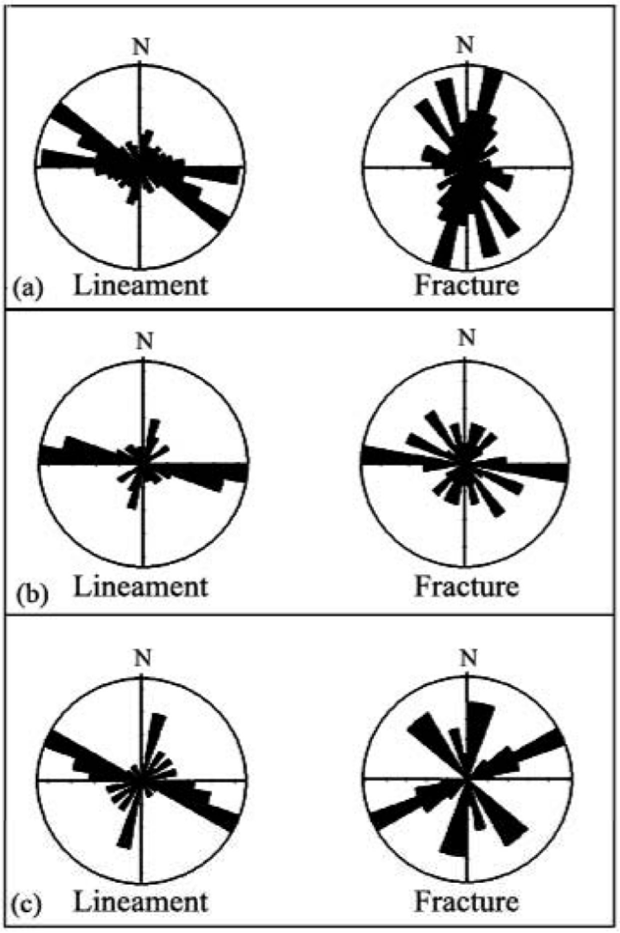

Fig.6. Lineament rosettes and fracture rosettes in (**a**) the northern domain (D1), (**b**) the shear zone (D2) and (**c**) the southern domain (D3). Dominant trends of lineaments and fractures are not parallel except in D2.

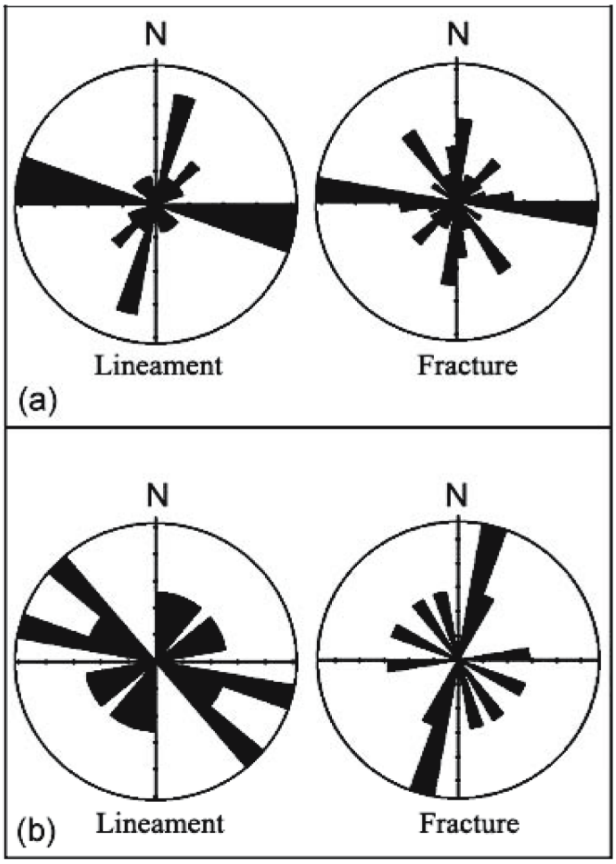

Fig.7. Azimuth-frequency rosettes showing lineament orientation and fracture orientation in mica schist. (**a**) within the shear zone and (**b**) outside the shear zone. Dominant lineaments and fractures are trending in the same direction within the shear zone only. Dominant trends of lineaments and fractures show discordant relationship outside the shear zone.

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 (Fig. 8) and compared with trends of lineaments of the corresponding domain, indicating foliation-parallel lineaments trending along E-W / NW-SE directions in D1 (Fig. 8a) and WNW-ESE in D3 (Fig. 8c). In D1, granite gneiss displays prominent alteration zones along the foliation planes (Fig. 9),

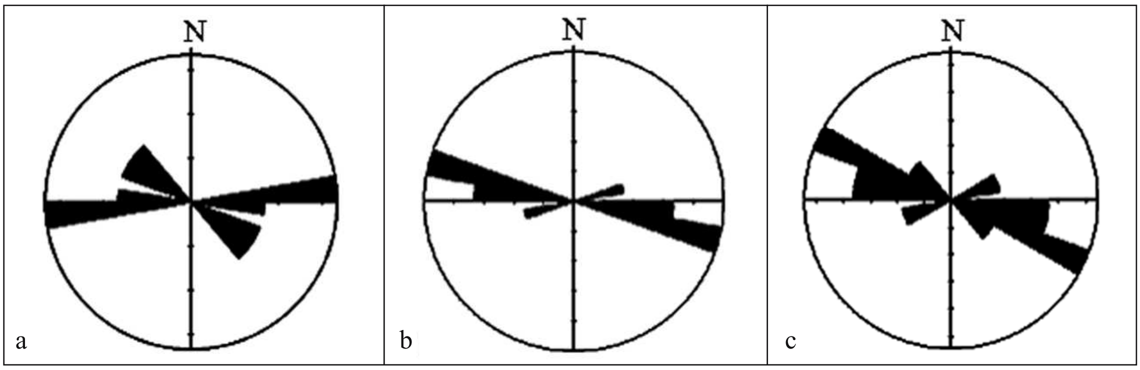

Fig.8. Azimuth-frequency (rose) diagrams of foliation orientation in **(a)** the northern domain (D1), **(b)** the shear zone domain (D2) and **(c)** the southern domain (D3).

Fig.9. Weathered foliation in granite gneiss – possible seepage pathway of groundwater.

developing lineaments parallel to 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'. In D2, E-W trending foliations (Fig. 8b) perhaps combine with dominant fractures to produce lineaments with high fracture correlation.

FRACTURE-FREQUENCY ANALYSIS

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. It is assumed that more closely spaced fractures with higher frequency may represent more potentially transmissive bed rocks (Mabee and Hardcastle, 1997). Though fracture frequency database is not very large the scatter-plots between fracture strike and fracture frequency for the domains, D1, D2 and D3, using Statistica software (Fig. 10) show a very interesting feature. The fracture set, striking E-W, exhibits higher frequency (>10/m) in the domain of shear zone (D2) (Fig. 10b), paralleling the trend of fracture-correlated lineaments. The hard phyllite / mylonite within shear zone exhibits high fracture frequency (Fig.11). In the domains D1 and D3, fractures show lower frequencies (<10/m) (figures 10a and 10c), except the N-S trending fractures in D3 which is typified by higher fracture-frequency (>10/m), perhaps corresponding to the N-S trending intermediate fracture-correlated lineaments in D3.

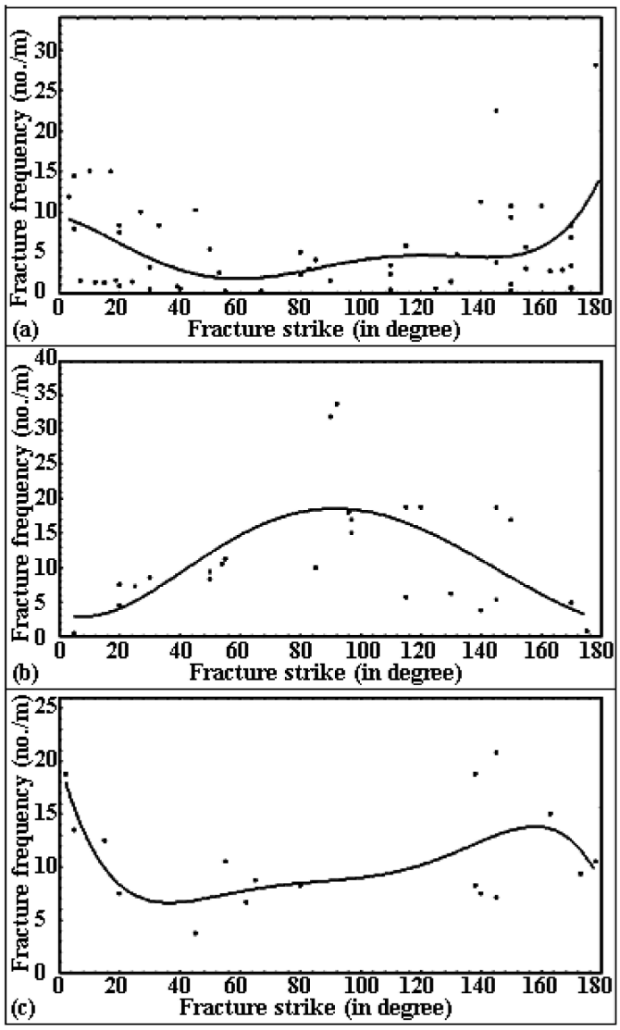

Fig.10. Graphs illustrating the relationship between Fracture frequency and fracture strike - (**a**) northern domain (D1), (**b**) shear zone domain (D2) and (**c**) southern domain (D3). D2 shows high value of fracture-frequency. D1 and D3 exhibit an overall low value of fracture-frequency except N-S direction in D3.

RESULTS AND DISCUSSION

One issue that we set out to address in this study was to assess the fracture-correlated lineaments and then relate the hydraulically significant fractures to the fracture-correlated lineaments. Unfiltered lineament analysis failed to identify overall correlation between lineaments and fractures. Filtered techniques locate the areas with similar trends of lineaments and fractures. The results of the comparative analysis among dominant lineaments, fractures, foliations and frequencies of fractures in each domain is tabulated in Table 1, showing fracture-correlated and foliation-correlated lineaments accordingly.

In northern domain (D1), granite gneiss clearly exhibits

Table 1. Comparative analysis among dominant lineaments, fractures, frequencies of fractures and foliations in each domain, designating lineaments as fracture-correlated and foliation-correlated accordingly

Domains	Trend(s) of dominant lineaments	Trend(s) of dominant fractures	Frequencies of dominant fractures	Trend(s) of dominant foliations	Designation(s) of lineaments
D1	(L1) – E-W, (L2) – NW-SE	(F1) –N-S	(F1) –<15/m	(FL1) –E-W, (FL2) –NW-SE	(L1) –foliation-correlated (L2) – foliation-correlated
D2	(L1) – E-W	(F1) –E-W	(F1) –>15/m	(FL1) –E-W	(L1) – fracture-correlated
D3	(L1) –WNW-ESE, (L2) –N-S (intermediate)	(F1) –NE-SW, (F2) –N-S	(F1) –<15/m, (F2) –>15/m	(FL1) –WNW-ESE	(L1) – foliation-correlated (L2) – fracture-correlated

dominant lineaments oriented along foliations rather than along the fractures with low fracture-frequency (<10/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. 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; Acharya and Mallik, 2012), forming foliation-correlated lineaments.

The shear zone (D2), comprising chiefly mica schist, shows strong concordance between trends of lineaments and fractures with high fracture-frequencies (>10/m) and the lineaments are 'fracture-correlated'. The mica schist has steeply dipping schistosity planes striking along E-W directions, paralleling the trend of SPSZ, a brittle-ductile shear zone.

In southern domain (D3), majority of the lineaments are facture non-correlated, oriented along foliations and, therefore, assigned as foliation-correlated. Intermediate fracture-correlated lineaments are concordant to the fractures characterized by high (>10/m) fracture-frequencies.

Fig.11. Shear zone rock i.e. hard phyllite/mylonite is showing very high degree of fracturing.

High fracture-frequency means closely spaced fractures. Several workers (Braathen et al., 1999; Henriksen and Braathen, 2006) have rightly pointed out enhanced permeability associated with the fracture sets that have high fracture-frequencies. Hydraulically significant fractures are flowing fractures characterized by increase in permeability, which appear to result from an increase in the density of fracturing, i.e. fracture frequency giving rise to higher connectivity of the fracture networks (Boutt et al, 2010). Evaluation of fracture frequency with structural domains yields significant trends. Hydraulically significant fractures with high fracture frequency are spatially closely related to the SPSZ (D2 domain) indicating the importance of this regional-scale structural element on permeability. Similar permeability structure has also been reported from the fault zones in Blue Ridge Province (Seaton and Burbey, 2005). Brecciated rocks adjacent to the shear zones, as well as the shear zones themselves, can be hydraulically conductive inducing preferential groundwater movement as suggested by several workers (Beamish, 1995; Choudhary and Kunar, 2007; Harinarayana et al. 2006; Rugh and Burbey, 2008; Seaton and Burbey, 2005, 2000) and form lineaments along fractures. Concentration of fracture-correlated lineaments in the shear zone corroborate with the locales of hydraulically significant fractures characterized by high fracture frequencies.

CONCLUSION

By using a combination of field-based geologic characterization and fracture-network data collection and analysis we have established the geologic controls on fracture correlation of lineaments and its relation to the concentration of hydraulically significant fractures in a fractured Precambrian metamorphic terrain. Filter analysis of lineaments clearly identifies the location of the fracture-correlated lineaments restricted within the brittle-ductile shear zone. Concentration of hydraulically significant fractures characterized by high fracture frequencies is also evident in the shear zone area. It may be concluded that the intense shearing, weathering of foliation planes and fracture-frequency may have played significant role in the occurrence of hydraulically significant fractures and fracture-correlated lineaments in the older metamorphic rocks.

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