An evidence of volume loss from ductile shear zone: A case study from Kengora shear zone of the South Delhi Fold Belt of Aravalli Delhi Mobile Belt, NW India.

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Abstract- The granite mylonite and deformed Gabbronorite-basic-granulite from Kengora shear zone in South Delhi Fold Belt shows the contribution of various deformation mechanisms to the strain geometry that developed during upper amphibolites/ granulite facies metamorphism in thrust related shear zones. The rocks contain good strain markers like well-defined mylonitic foliation, stretching lineation, asymmetric porphyroclasts, quartz and feldspar ribbons, mica fish. The shear zone shows NW thrust slip character. Dynamically recrystallised quartz and feldspar grains show strain ratios varying from 1.0 to 2.5 for X/Z sections and 1.0 to 1.5 for Y/Z sections. Using these strain ratios the Legarath Fhnn plot was drawn, which shows an apparent flattening strain with volume loss for all the samples. The volume loss is proportional to the strain rate and thus progressively increases towards the centre of the shear zone. The shear strain varies (0.07 to 4.98) across the shear zone and is maximum in the ultramylonite zone. The angular displacement also varies along the strike of the shear zone (1.7-1.8 km).

Key words: Aravalli Delhi Mobile Belt, ductile shear zone, mylonite, South Delhi Fold Belt.

I. INTRODUCTION

Ductile shear zone are very common features in crystalline rocks that have undergone deformation at moderate to high temperatures (Choukroune & Gapais 1983; Ramsay & Allison 1979). They vary in width from millimeters to kilometers and displacements along them may vary from the same order of dimension (Ramsay & Graham 1970; Coward 1976; Bell 1981; Mohanty & Ramsay 1994). The foliation within a shear zone may develop in a heterogeneous way, giving rise to S-C fabric (Burke et al., 1979). In the present work, we are highlighting the volume loss with increasing shear strain from the Kengora shear zone (KSZ) of the South Delhi Fold Belt (SDFB). These rocks present advantages for analysis because they posses well-defined mylonitic foliation, stretching lineation, asymmetric porphyroclasts, quartz and feldspar ribbons, which make good strain markers.

II. GEOLOGICAL SETTING

The Precambrian terrane of northwestern India includes an Archean basement (3.3 – 2.5 Ga) and overlying Proterozoic Aravalli and Delhi Fold Belt (Heron, 1953). The Delhi Fold Belt (DFB) is dominated by anamorphic facies in the north and has been classified as North Delhi Fold Belt (NDFB); the southern part is dominated by calcareous facies and metavolcanics and is known as South Delhi Fold Belt (SDFB) (Sen et al., 1981; Desai et al., 1978; Sinha Roy et al., 1998; Srikumari et al., 2004). The granulite terrane lies within the southern part of the SDFB. The pelitic granulites, calc-granulites, gabbro-norite-basic-granulite suite (GNBK) constitute the major rock types in the terrane. The granulite terrane is surrounded by low grade rocks such as mica schist, calc schist, amphibolite and metatuffite. The granulites are intruded by three phases of Aharaj granites, the G1 phase is produced from the necking of the pelitic granulites and show an age of ca. 840 Ma; G2 occurs as large scale batholiths showing an age of ca. 800 Ma and the G3 phase occurs as dykes and linear bodies showing an age of ca. 750 Ma (Gupta et al., 1980; Choudhary et al., 1984; Deb et al., 2001; Singh et al., 2010; Just et al., 2011). In the study area, the granulites have undergone three stages of folding (Biswal et al., 1988). First and second phases of folding are coaxial and their fold axes are gently plunging towards NE. The third one is crenulation folds and kink bands (Singh et al., 2010). Superposition of F1 and F2 has given rise to type 1 interference pattern or hook pattern in small to large scale. Shearing has occurred parallel to the axial plane of the F2 fold and large scale shear zones are developed during this period of folding. F1 on F2 has produced type 1 interference pattern or dome and basin structure, whereas F3 on F2 has produced minor image or type 2 interference pattern. The granulite terrane is traversed by many shear zones, Sansi shear zone (SSZ), Kengora shear zone (KSZ) and Ghoda shear zone (GSZ) (Fig. 1a,1b).
Figure 1a: Geological map of the study area showing different types of rocks and shear zones (modified after Sing et al., 2006).Inset (i): Map of India showing the location of the study area.

Figure 1b: Structural map KSZ of the SEFBs showing the sample locations across the strike of the shear zone.
Stereonets (i)&(ii): Mylonitic foliation and Lineations data from KSK and LSK traverses.
Figure 2. Photomicrographs of the KSG showing NW vergence of the thrusts. (a) S-C fabric in the granite mylonite, (b) Asymmetric porphyroclasts, (c) Low angle mitringular fault, (d) hornblende foliation and quartz ribbons.

Figure 3. (a) Logarithmic Haim's plot shows the 4-25% volume decrease in all the samples. (b) Plot of k vs. r show oblate strain for deformed rocks.
III. STUDY AREA

We have studied a 2 km length of extensive shear zone which is nearly the width of 700 meters. The shear zone strikes NW-SE with a moderately dip towards ENE (Fig. 1a, 1b). Also shear zones are often found in an anastomosing pattern due to non-uniformity of stress distribution during deformation which is common in shear zones.

A. Rock types

The rock types in the shear zones vary depending on the host rock over which it has been developed (Fig. 1a, 1b). While protomylonite, ortho and ultramylonite are developed in granites, the GNBG are also extremely sheared.

B. Macro- and micro-scale structures of the shear zone

The characteristic macroscopic and microscopic structures of mylonites are well exposed in the study area and studied in details on L and T section of mylonites. This study reveals the variation in microstructure in the shear zone as well as variation in strain characteristics. It is found that with the progressive increase of distance from the shear zone wall there is variation in structure. Initially there were foliated grains of feldspar and recrystallized grains of quartz. Then there was strain concentration, which caused polygonization of grains in places. At the most interior part there are quartz ribbons showing recrystallization showing grain boundary migration or grain boundary rotation. This total process comes under dynamic recrystallization. The important microstructures found in the rocks are described below.

Protomylonite have a weak foliation and quartz grains are lensoidal with a strong preferred grain shape orientation. The mylonite foliations are characterized by enrichment in mica and quartz, feldspar ribbons becomes progressively better developed towards the centre of the shear zones, where the aspect ratio of the aggregates is highest and inclination of the long axes of the aggregates to the boundary of the shear zone is smallest. In the centers of some of the sheared zones, the feldspar aggregates are undistinguishable. The angle between the foliation and the shear zone boundaries varies from about 45° near the shear zone boundary to about 11° at the center of the shear zone. An angular relationship between C- and S-surfaces indicates a southwards sinistral sense of shear. Occasionally, shear band clays are developed parallel to C-planes due to low angle warping of the S-fabric. Asymmetric porphyroclasts, microfaults, mica fish and horemb and fishs point towards NW vergence of shearing (Fig. 2a, 2b, 2c, 2d).

IV. STRAIN ANALYSIS

In this paper, strain analyses have been performed on 12 samples of granite mylonite and highly deformed GNBG taken from the K and L traverses from the KSZ (sample locations are shown on Fig. 1b). Strain within the shear zone is extremely variable and the transition from protomylonite to mylonite and ultramylonite is commonly observable in outcrop.

A. Volume loss calculation from logarithmic Fliess diagram as well as ductile band structures

The In (X) vs. In (Y) plot is used to determine volumetric deformation (Fliess, 1962; Ramsay and Wood, 1972; Schwerdtner, 1976; 1982; Mawer, 1983; Bailey et al., 1994). The results of the strain analysis are presented in Table 1 and graphically in Fig. 3a. All samples display oblate (type of strain ellipsoid) and belong to apparent flattening field. Volume losses (Δ) were calculated using the measured strain value and equations derived from the theory of hand structures (Ramsay and Wood, 1973; Schwerdtner, 1977, 1982).

Both the cases, it is found that the samples show different degrees of volume loss (4-25%) and there is general increase in volume loss towards the centre of the shear zone. Hence, it is approved, that the Δ is proportional to the strain rate (Ramsay and Huber, 1987). In addition, the parameter k (strain ellipsoid) is less than 1.0 and parameter r measured of the strain intensity (Watterson, 1968), shows variation from 1.08 to 2.41. With increasing r value, the k value increases suggesting that the strain becomes less oblate with progressive deformation (Fig. 3b).

B. Evaluation of Strain

The strain in the KSZ is presumed to be simple shear because the shear zone exhibits a gradual increase in shear strain from the margins to the center similar to the shear zones described by Ramsay and Graham (1970). Systematic variation of C- angle is noted from wall to the center (Table 2). The strain is calculated by using S-C angles, measured in the samples collected almost at regular interval across the shear zone, by using the following equation:

\[ \gamma = 2 \cos 20 \]  

(1)

(Ramsay and Huber, 1983; 1987)

Where, γ is the shear strain and θ is the angle between the foliation (S plane) and shear zone boundary (C plane). Two profile lines were drawn at 500 m interval and sample spacing were maintained at 100-120 m approximately. The average dip of the shear zone varies along the strike length as follows: K1 = -76°, L1 = 65°. The true width of these traverses as is as follows: K1 = 650 m, L1 = 675 m (Fig. 4a, 4b). From these figures the average true width for the KSZ is
found to be 683.5m. In Fig. 4c, 4d graphs have been made by plotting shear strain against sample locations on true width line. The graphs show a gradual increment of shear strain from the wall towards the centre. The maximum shear strain is obtained 4.55 along K1, traverse. From the above shear strain values the angular displacement is calculated from the equation,

$$\psi = \tan^{-1} \gamma$$

(Ramsay and Huber, 1983; 1987)

Where, $\psi$ is the angular displacement. The S/C angle, $\gamma$ and $\psi$ values are listed in Table 2. The angular displacements at each sampling site are graphically integrated over the entire width of the zone to calculate the total displacement for each profile (Fig. 4c, 4d). The displacement lies in the range of 1.7 km to 1.8 km. However, it is confirmed that variation of shear strain is not exactly similar along all profiles suggesting variation in amount of throw in different parts of the shear zone.

V. DISCUSSION

The KSZ has an overall NW-SE strike and dip varies along its strike. This is because of foliations planes which are dipping at a very high angle, so during deformation or shearing, deviation of the foliation plane might have taken place in some part of the shear zone due to non-uniformity of stress distribution during deformation. From the location data and the shear sense indicators it can be interpreted that it is a high angle oblique slip reverse slip thrust fault. Thus it has been inferred that the granulite block has been thrust up over the low grade rocks to the west. Logarithmic strain diagram shows that there is volume loss in all the samples and it increases (4 - 25%) towards the centre of the shear zone. The S-C angle plot in the shear strain vs. true width of the shear zone shows that the shear strain varies (0.07-4.95) across the shear zone and it is maximum in the central part of the shear zone. The angular displacement also varies along the strike of the shear zone (1.7-1.8 km).

VI. CONCLUSION

1. This is a granulitic shear zone marked by thrust tectonics. Due to imbricated nature of thrust this process has been applied on the underlying slab. As the huge overburden of granulitic mass rode over the granulite slice and it squeezed the intervening rocks. So the underlying slab undergoes volume loss.
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[List of acknowledgments]

Table 1. Measurements of X, Y, Z, and T at different locations along the fault and in different planes.

<table>
<thead>
<tr>
<th>Measurement</th>
<th>Location 1</th>
<th>Location 2</th>
<th>Location 3</th>
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<tbody>
<tr>
<td>X</td>
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<td>3.4</td>
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<tr>
<td>T</td>
<td>4.5</td>
<td>6.7</td>
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[Table continues with more measurements]

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