Evidence of ductile shearing from the extensional crenulation cleavage: An example from Zawar area, the Aravalli mountain

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Extensional crenulation cleavage marked by asymmetric kinks and ductile shears occurs at low angle to steep S1 planes in the mica schist of Zawar area in the Aravalli mountain. It is developed due to extension along the S1 planes consequent to large-scale ductile shearing. The compressive stress of such shearing is deduced to be subhorizontal in NNE-SSW direction. Early fold axes assume variable trend due to shearing.

Small-scale microfolds, termed as crenulation, develop on pre-existing slaty cleavage or schistosity due to superposed folding. The rocks, with crenulations, have a striped appearance due to the preferential localization of mica flakes in the limbs-cleavage domain of such folds. The cleavage domains are discrete and often marked by shear fractures. These constitute the crenulation cleavage (CC) and bear similar significance as axial plane cleavage. The coarse fold planes, enriched with quartz, between the cleavage domains define microlithons. The CC is genetically related to buckling where a multilayered sequence undergoes layer parallel shortening. Extensional crenulation cleavage (ECC) morphologically resembles a normal CC. However, they occur at a low angle (< 45°) to s-planes compared to high angle of disposition (45° to 90°) of the other. ECC owes its origin to shortening normal to s-planes (i.e. extension along layering) and the associated microfolds (single or conjugate kinks) develop because of shearing. A type of internal buckling may also be caused by extension along foliation to develop such microfolds. The ECC is synonymous to shear band cleavage or 'C' fabric in a ductile shear zone and is analogous to the structure proposed by Means and William with a layer normal shortening in salt mica multilayer. We report here ECC from Zawar area which evidences ductile shearing in this part of the Aravalli mountain.

Zawar is 35 km south of Udaipur in Rajasthan and is well known for Proterozoic Pb-Zn mineral deposit. The area is represented by Aravalli Supergroup of rocks, including mica schist, dolomite and quartzite, which are impressed upon by polyphase deformation (Figure 1). Summarily, the area shows the presence of three generations of folding. The first generation folds, F1, are isoclinal and predominantly oriented in WNW-ESE direction (Figure 1A). The dominant schistosity, S1, is axial planar to this fold. The F2 and F3 folds, representing the second and third generation structures, are in NNE-SSW and WNW-ESE directions respectively. Crenulation and fracture cleavages mark the axial direction of F2 and F3 folds. This property is used to differentiate the F3 axial planar cleavage from that of F1, though they trend in the same direction. Apart from this, wide-scale ductile shearing parallel to the axial plane of F3 fold is observed constituting a prominent ductile shear zone in the study area (Figure 1, near Harm Magra). Offsetting of the bedding planes and quartz veins, presence of S-C fabric and, rotation of fold axis and intersection lineation of first generation from NNE-SSW direction in the east and to northwesterly direction in the west characterize

Figure 1. Geological map of Zawar area (Insets. Map of India for location of Zawar. A, 115 F1 axial plane and S1 schistosity, maximum strikes in WNW-ESE direction, contours:1-3.5-7% of 1% area; B, F3 conjugate axial planes with the spot S1 plane; α1, α2 and α3 indicate the direction of maximum, intermediate and minimum compressive stress respectively.)

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this WNW-ESE striking shear zone. The ECC, which constitutes the theme of this paper, occurs in steeply dipping mica schist of Harn Mogra and provide meso- and microscopic evidence of ductile shearing during F3 folding. The F3 folds occur in very large scale to meso- and microscopic crenules and kinks. The cleavage domains in the crenules are marked by localization of micas and shear fractures. These are discrete and anastomosing in nature, bounding well-marked microlithons. From the mesoscopic conjugate kinks, the maximum compressive stress for F3 folding is deduced to be subhorizontal in NNE-SSW direction (Figure 1 B). The cleavage domain subtends a low angle (0 to 30°) with the steep S1 planes. The flattening direction of shear fractures in this cleavage zone lies almost along the S1 planes and hence this cleavage cleavage is referred to as extensional cleavage cleavage (ECC). The oblique intersection of anastomosing ECC with S1 planes imparts a fish scale or button schist structure, very conspicuous in the area. The mesoscopic chevron F2 folds are traversed by close-spaced fracture cleavages and through detailed observation, these folds emerge to be class 2 type15, i.e. similar fold (T' = 1). This bears resemblance with slip folding where the fractures seem to have acted as slip planes. Furthermore, while unfolding, the F2 intersection linations on the F3 folded surface trace a curved line, implying that the F3 folding is caused probably by heterogeneous simple shear.

The microscopic characters of ECC are as follows:

1. The S1-fabric carrying ECC is marked by parallel alignment of biotite, muscovite and flattened quartz grains.
2. The ECC is marked by asymmetric kinks and monoclinal flexures on S1 planes with or without shear fractures (Figures 2, 3). The axial plane of such kinks makes 15° angle with S1 planes, the inter-limb angle varies between 90° and 120° (Figure 2) and the steeper limbs carry the cleavage zones (ECC). Where shear fractures are abundant (Figure 3) they displace and draw the mica flakes into their alignment and the cleavage zones at places merge with the S1 planes.
3. The ECC is discontinuous and anastomosing; the anastomosing ones enclose lensoidal body providing an augen or phacoidal texture to the rock (Figure 3).
4. The microlithon portion is constituted of coarse mica and quartz grains (Figure 2). While the quartz grains within the microlithons are relatively strain free, they are flattened and show strong undulose extinction close to the sheared cleavage zones.
5. The monoclinal flexures of S1 planes within two bounding ECC resemble a shear zone (Figure 3). The shear sense deduced from the acute angle relationship16 for different spots emerges to be both dextral as well as sinistral. By constructing strain ellipsoid for such shear, the elongation is found to lie parallel to the S1 plane.
6. Pyrite grains occur as porphyroclasts flanked by strain fringes17 which are arranged asymmetrically to ECC, suggesting rotation of the pyrite during shearing.
7. Pull-apart micas are developed between two shear planes, reflecting transdistinctive condition during shearing.
8. Neo-chlorite and biotite grains are developed along the ECC, demonstrating a slight change in bulk composition during its development.
9. Sigmoidal porphyroclasts, with a sinistral sense of shear, are also noticed (Figure 3).

The high angle orientation of principal compressive stress to the S1 planes belies the buckling origin of F3 folding. As the ECC is characterized by ductile shearing and the flattening direction of such shear remains along S1 plane, shearing has obviously contributed to its de-
velopment. Hence, apart from the microfolds, monoclinal flexatures on S1 planes are visible within two parallel shear planes. The slip nature of mesoscopic F2 folds, as evident from unrollable nature of early lineations, subscribes to shearing phenomenon. These ECC, hence, represent the 'C' fabric or shear bands15 of a ductile shear zone. The variation observed in the axial orientation of F1 and F2 folds in different parts of the study area is primarily attributed to such shearing. This shear zone may be parallel to one marked in north of Mochia11 (Figure 1).


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