from a snail shell. The snail shell is approximately a two-dimensional spiral. In case of the conch shell, the spiral coils around a central axis called the columella or central pillar of the shell. Figure 1 *a–c* clearly shows that the cavity around the central pillar grows both in the horizontal and vertical directions. Results of measurement of longitudinal and transverse cavity dimensions according to labels in Figure 1 *a–c* are shown in Tables 1–3 respectively. It may be noticed that the ratios of selectively taken parameters fall fairly close to the golden value.

The golden ratios are nearly borne out in all the tested samples. It has also been checked by matching the X-ray tomographs with the computer-generated spiral that the curves ab, cd, ef, gh, ij, kl, mn in Figure 1 *a* and *b* exactly fit with appropriate sections of the spiral.

We have shown that the spiral structure of the conch shell clearly exhibits Fibonacci pattern. Our study has been limited to a few samples of conch shells. But in view of the symmetry of conch structure, we deem the findings to be a generalization. However, deviation might be possible in certain conch species.

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Ductile shearing along the Great Boundary Fault: An example from the Berach river section, Chittaurgarh, Rajasthan

The Great Boundary Fault manifests itself as a northeast striking tectonic lineament that cuts the Precambrian crust in Rajasthan for strike length of more than 400 km. Geophysical studies indicate that this fault continues under the Gangetic alluvium[1], dips at a steep angle towards northwest and cuts a thick section of the crust up to a near Moho depth[2–4]. That the Great Boundary Fault has developed as a consequence of brittle style of deformation is well entrenched in geological literature since the pioneering contributions[5–11]. There has, however, been considerable controversy regarding the initiation and reactivation of this fault, i.e. normal to reverse[12], or, thrust to normal[13]. Palaeostress analyses reveal that the tectonic evolutionary history of the Great Boundary Fault records three distinct phases of reactivation, each typified by a characteristic style of brittle faulting[14]. A recent study indicates the ductile nature of deformation in the Upper Vindhyan and the Ranthambore Groups of rocks, exposed in the vicinity of the Great Boundary Fault[13]. Here we report the occurrence of mylonites in the Lower Vindhyan rocks, and demonstrate that ductile shearing, responsible for the development of these mylonites, is the earliest event of tectonic deformation within the Great Boundary Fault zone.

Two distinct types of deformation zones[15] can be identified within the study area (Figure 1 *a*). First, an approximately 150 m wide fault zone, namely the Great Boundary Fault Zone GBFZ, which is characterized by the occurrence of numerous metre-scale ductile shear zones, two groups of successively developed mesoscopic folds, F_1 and F_2 and the intense nature of F_2 folding. Second, an approximately 5 km wide fault-related deformation zone, which consists of metre-scale brittle faults and en-echelon veins that cut through kilometre-scale F_2 folds[14]. In the fault-related deformation zone, F_1 folds and ductile shear zones are characteristically lacking, and F_2 folding is distinctly less intense than the F_2 folding in the fault zone. Here we focus on the nature of deformation within the GBFZ, which cuts through the Nimbahera shale beds exposed in the Berach river section (Figure 1 *a*). The nature of deformation within the fault-related deformation zone has been described elsewhere[14].

It is noteworthy that the GBFZ in the Berach river section cuts through the Vindhyan rocks rather than following the contact between the Berach granite and the Vindhyan sedimentary rocks[11,12] (Figure 1 *a*). The outcrop pattern within the GBFZ is controlled by characteristically open to gentle and upright F_2 folds that plunge at low angles towards NE and/or SW (Figure 1 *b* and *c*). Many of these folds define periclinal domes and basins, and the individual fold hinge lines commonly bifurcate at moderate angles (*c*. 45°). Several lines of evidence, such as the direct relationship between thickness of beds and wavelength of folds, the branching of hinge lines, the reversal in sense of shear offset at the opposite limbs, and the orthogonal relationship between the hinge lines and striations on the fold limbs imply that these folds were developed by flexural slip mechanism due to layer parallel compression.

Ductile shear zones, the other major characteristic structure of the GBFZ in the Berach river section, occur as metre-scale

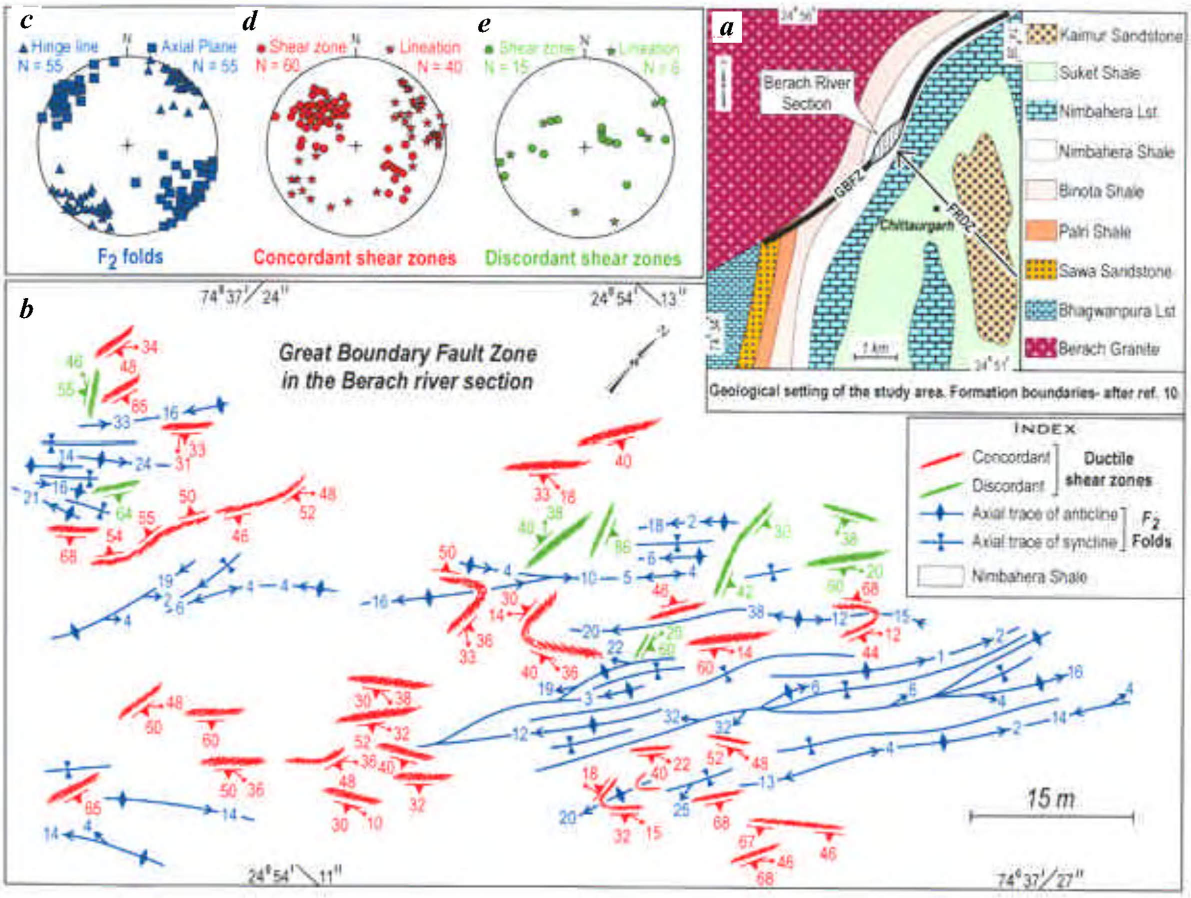

Figure 1. ***a***, Geological setting of the Great Boundary Fault Zone (GBFZ) and the fault-related deformation zone (FRDZ) around Chittaurgarh area. Berach river section of the GBFZ defines the study area. ***b***, Structural map of the GBFZ. Orientations of mylonite foliation and stretching lineation in concordant and discordant ductile shear zones are shown in red and green respectively. Axial traces and plunges of F_2 folds are shown in blue. ***c–e***, Lower hemisphere, equal area projections for poles?; F_2 axial planes and hinge lines; concordant shear zones and stretching lineations, and discordant shear zones and stretching lineations.

lensoid or tabular zones that consist of well-developed mylonite foliations and stretching lineations, and cut sharply through the Nimbahera shale (Figure 1 *b*). Depending upon whether a shear zone is parallel or athwart to the bedding surface, it is classified as concordant shear zone or discordant shear zone respectively (Figures 1 *b*, *d*, *e* and 2). As the cross-cutting relationship between concordant and discordant shear zones is inconsistent, these two types of shear zones are inferred to have developed synchronously. A few concordant shear zones are found to grade into discordant shear zones along their strike continuity. Variation in the orientation of mylonite foliation at the scale of the GBFZ is due to the combined effect of F_2 folding and the discordant nature of some shear zones. The stretching lineations exhibit a wide scatter in orientation (Figure 1 *d* and *e*) and the shear sense indicators imply inconsistent sense of movement, because the mylonite foliations have been deformed successively during F_1 and F_2 folding. It is, therefore, difficult to decipher the original direction and sense of movement on the ductile shear zones.

The ductile shear zones are predominantly made up of two compositionally contrasting bands that are distinct at both mesoscopic and microscopic scales: (i) well-foliated quartz bands developed due to mylonitization of quartz veins, and (ii) massive, brown-coloured, fine-grained, opaque bands containing relict fragments of the Nimbahera shale. Microstructural studies reveal that the quartz bands are predominantly made up of quartz ribbons showing undulose extinction, subgrain development, deformation lamellae, serrated grain boundaries, *S–C* fabric and mortar texture. These microstructures imply that crystal plasticity and dynamic recrystallization were the dominant mechanisms of deformation during the mylonitization process (Figure 2 *b–d*). Brown bands are formed due to the concentration of opaque minerals and dark residue remaining after dissolution of light coloured and readily soluble minerals in the Nimbahera shale during the development of quartz veins and ductile shearing.

The F_1 group structures comprises two successive generations of mylonite foliations, m_1 and m_2, and two sets of isoclinal folds, F_{1A} and F_{1B}. The earliest recognizable tectonic fabric, m_1, in the GBFZ, was formed due to bedding parallel ductile shearing within the local domains of the Nimbahera shale beds. With the advancement in progressive ductile shearing, m_1 was folded into F_{1A} isoclinal folds. Continuation of ductile shearing, subparallel to F_{1A} axial planes, resulted in transposition of F_{1A} isoclinal folds and development of a new mylonite foliation m_2 (Figure 2 *d*). With further advancement in ductile shearing, a new set of isoclinal folds F_{1B} formed

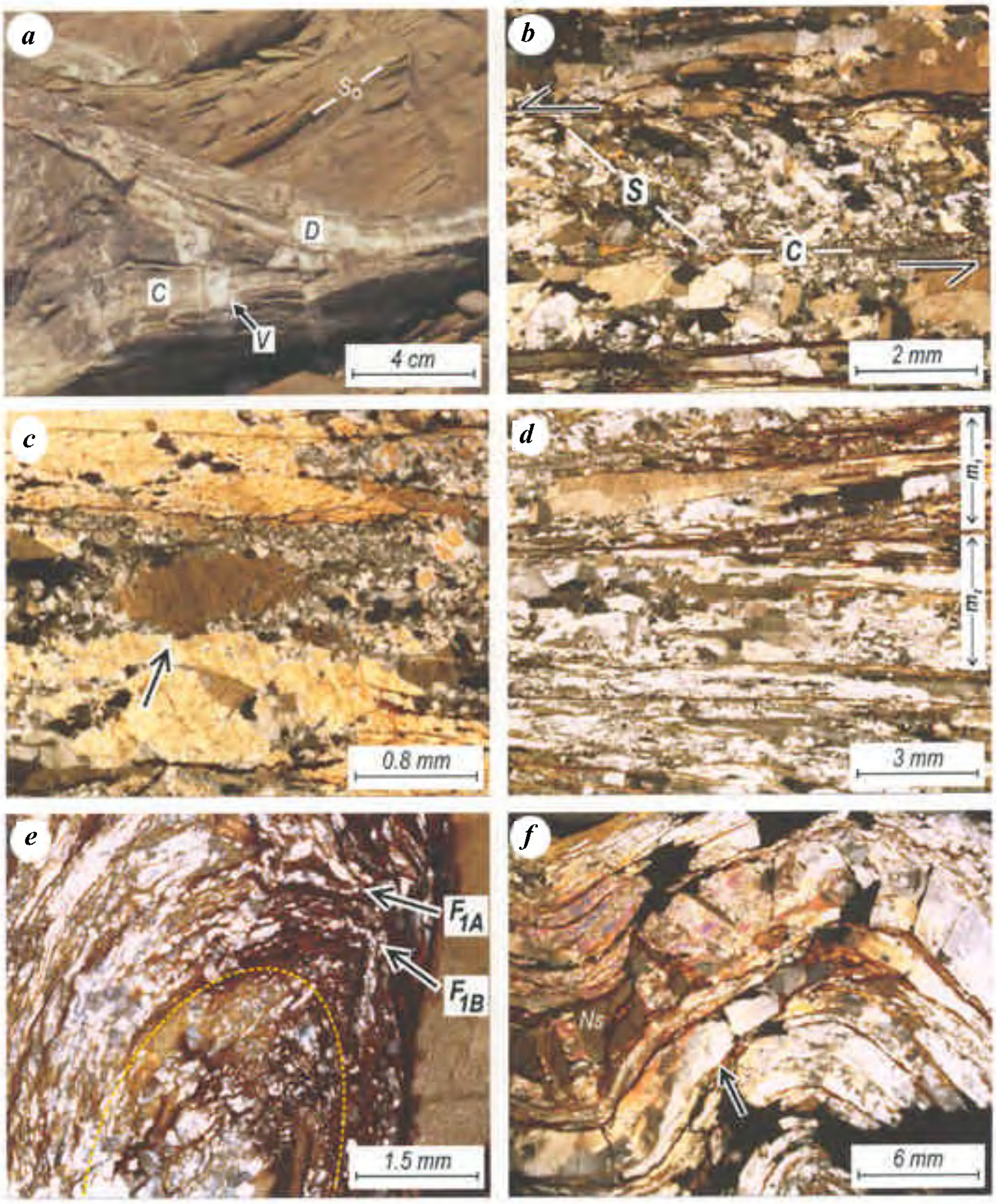

Figure 2. ***a***, Concordant, *C* and discordant, *D* shear zones in the Nimbahera shale. S_0, bedding surface; *V*, Bedding perpendicular quartz vein. ***b***, *S–C* fabric. ***c***, Mortar texture (arrow) shows a quartz porphyroclast and recrystallized quartz grains along its margin. ***d***, Late mylonite foliation m_2 cuts through the early mylonite foliation m_1 ***e***, Type-3 interference pattern between F_{1A} and F_{1B} folds on the mylonite foliation. The trace of F_{1B} isoclinal fold is highlighted by yellow line. ***f***, F_2 fold traced by quartz ribbons (arrow) defining mylonite foliation. Ns, Relict fragment of Nimbahera shale.

on m_2 and the vestiges of F_{1A} isoclinal folds were refolded by F_{1B} folds.

The common occurrence of type-3 interference pattern between the F_{1A} and F_{1B} folds implies a coaxial relationship between these two fold sets (Figure 2*e*). All preexisting planar structures, namely, the bedding surfaces S_0, and the successive mylonite foliations m_1 and m_2, were buckled during F_2 folding, which post-dated the event of ductile shearing (Figure 2*f*). It is because of type-2 interference between F_1 and F_2 folds that the F_1 group of folds exhibits a characteristic non-plane and non-cylindrical geometry.

Overprinting of ductile shear zones by brittle structures, such as fractures and faults belonging to multiple phases of reactivation, suggests that ductile shearing represents the earliest event in the tectonic history of the Great Boundary Fault. These ductile shear zones were typically formed in the local domains of the Lower Vindhyan sedimentary rocks. As most of the ductile shear zones were initiated as a result of bedding parallel shearing, concordant shear zones are most common. A few shear zones that initiated at an angle to bedding surfaces are now mappable as discordant shear zones. Shear zones that initiated partly parallel and partly at low angle to the bedding surface, occur as concordant shear zones grading into discordant shear zones.

The following processes are inferred to have operated either successively or in partly overlapping manner, during the evolution of ductile shear zones. (i) Development of extensional and shear-extensional fractures at moderate to high angles with respect to the bedding surfaces. (ii) Pressure solution and channelized flow of the syntectonic fluids, which resulted in dissolution of readily soluble constituents, such as SiO_2 from the Nimbahera shale, and development of quartz veins due to precipitation of SiO_2 in the fractures. The residues of relatively undissolvable iron oxides constitute bulk of the brown bands occurring within the shear zones. (iii) Development of bedding parallel mylonite foliation through dynamic recrystallization and intracrystalline plastic deformation of vein quartz.

With these observations, we conclude that the tectonic evolutionary history of the Great Boundary Fault consists of an early event of ductile shearing and the late events of successive reactivation by brittle faulting[14]. The microstructural lines of evidence suggest that the ductile shearing reported here, occurred in a shallow crustal and low-temperature environment.

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