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Interactive comment on "Control of pre-existing fabric in fracture formation, reactivation and vein emplacement under variable fluid pressure conditions: An example from Archean Greenstone belt, India" *by* Sreyashi Bhowmick and Tridib Kumar Mondal

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We thank the reviewer for his extensive review, and many constructive comments. Although it is suggested for a moderate revision, we believe that the comments have made us to think more deeply and have helped in revising the manuscript considerably. We have implemented, most of the changes suggested and addressed some of his points in details, below. In other cases, we clarified our arguments.

At first, we outlined the main issues that we have addressed in the revision, followed by comment wise response to the minor issues raised by the reviewer.

Response to main Issues

Issue-1: Fault-valve action. The reviewer has raised his first concern on fault-valve action and commented "Fault valving: the authors propose that fault valving was the driving mechanism to pump fluids. I think this may be possible but both "fragments of host rock" occurrence within veins and mutually cross-cutting relationships are not exclusively indications of fault-valving. These may also indicate a very high fluid pressure surge and "hydrofracturing" of the host rock (fragments) and coeval emplacement of all the veins (mutual crosscutting veins). Probably a fabric analysis of vein may disentangle this point, the occurrence of crack and seal textures in the veins may clearly indicate cyclic fluid ingressions and fault valve mechanism."

Yes, we do agree with the reviewer that the presence of host rock fragments in quartz veins and mutually cross-cutting relationships does not exclusively indicate fault-valve action. Therefore, as suggested by the Reviewer, in the revised manuscript we have incorporated a new supplementary sheet-2, consisting field photographs of metabasalt hosting quartz veins with multiple median lines. This exemplifies crack seal texture in the veins, thereby clearly indicating cyclic fluid ingression and fault-valve action that led to the formation of veins in the metabasalts of the Chitradurga region.

Issue-2: Cluster analysis The reviewer has pointed out a number of clustering of veins in the lower hemisphere equal area projection and mentioned that "In analysing the veins distribution the authors define a clear vein cluster (NNW-SSE veins). If the Jolly and Sanderson method is applied to a cluster of vein clearly it will indicate a cluster distribution. So it is not possible to differentiate different epi-sodes of fluid injection from a large single event where most of the fluid injected the well-oriented NNW-SSE trending fractures (they attain also the maximum vein thicknesses) and also reactivated the other fractures. Moreover, other clusters are apparent in the distribution (for example that around the s2 pole). I suggest to expand the cluster analysis of the data sets and to apply the Jolly and Sanderson method to all the clusters and also to the data set minus the NNW-SSE cluster."

Yes, there are a number of clusters, however the WSW cluster is quite prominent with a very high cluster density as compared to the rest. This was the motivation behind primarily considering the WSW cluster for analyzing the fluid pressure condition. Although, it is critical to differentiate various episodes of fluid ingression from a single large event. Therefore, in accordance with the suggestion made by the reviewer we have expanded the analysis and incorporated the other clusters (such as the NE and the SE clusters) in the lower hemisphere equal area projection of pole to veins. The supplementary sheet-3 provides all the cluster analysis in this regard. In the revised manuscript we have incorporated the same and changes have been made accordingly which definitely increases the clarity of the manuscript.

Response to minor comments

Apart from the above comments the Reviewer has commented few more in the specific line positions of the manuscript, which are listed below.

Lines 47-48. This is not completely true. Fault valve action develops when fluid pressure shows a cyclic increase. All veins forms because of dilation of fracture's walls. Please reword the sentence.

Reply: We have reframed the entire sentence in the revised manuscript as suggested by the Reviewer.

Lines 55-58. not clear, please reword.

Reply: The sentences have been reframed in the revised manuscript.

Line 124. angular enclaves suggest high fluid pressure at the time of vein formation with rupture of wall rocks (hydrofracture). Fault valving is testified by crack and seal fabric of veins. The occurrence of striated veins suggests active stress field after the vein formation.

Reply: This is one of the major issues suggested by the Reviewer. This has been previously addressed in Issue-1: Fault-valve action, and accordingly a supplementary data sheet-2 has been added with the main manuscript as a response to the comment. The process of fracturing, fracture reactivation/faulting along with vein emplacement prevailed in an active stress field as pointed out by the Reviewer.

Lines 147-148. this is not clear. Why mutually cross-cutting relationships do imply several cycles of emplacement? It is possible that this pattern of veins indicates a coeval formation of veins?

Reply: At high fluid pressure condition (supra-lithostatic levels), Pf exceeds the stresses acting on the fracture/fault plane, thus causing failure and forming mesh of fractures. Subsequently, the fluid flows into this mesh of fractures, a phenomenon analogous to “burping” (Sibson and Scott, 1998), and the fluid pressure drops. The veins seal the fractures/faults, and the system is once again ready for the next cycle of fluid pressure build-up, failure, fluid flow (burping) and subsequent vein formation. This phenomenon involving repeated cycles leads to crosscutting veins and fractures (mesh-like structure; Mondal and Mamtani, 2013; Sibson, 2004 and the references therein). Under successive low Pf conditions, the orientations represented by the individual clusters (WSW, NE and SE) were reactivated selectively depending on their respective orientation to the tectonic stress field and the fluid pressure magnitude.

Lines 256-259. This is an important point. Looking at the veins’ pole distribution also a cluster around the intermediate stress (s2) is apparent. Construction of data set from clustered data clearly will lead to a cluster distribution. I suggest here to provide a clear cluster analysis of the data and to extend the analysis to all the resulting clusters. Once these results are obtained, the question to face is: are these different pluses of fluid injections? Is clustering inherited by the fracture network exploited by fluids?

Reply: All the respective clusters have been separately evaluated as suggested by the Reviewer (supplementary sheet-3). Fluid pressure conditions (Pf) are determined discretely for each of these clusters. The variation in Pf clearly indicates the existence of different pulses of fluid injection. All such orientations represented in the cluster have been exploited by fluids as evident from vein emplacement along these orientations. However, the maximum vein thickness is recorded along NNW-SSE direction.

Lines 348-356. These sentences are repetitive. You may expand the geological background and cut off here these sentences.

Reply: The sentences that are repetitive have been omitted as suggested by the Reviewer.

Line 387. This is ok from a tectonic point of view. Now rocks are exposed. When did rocks' exposure occur? Unloading form a few kilometres to the surface did not generate any jointing? This point here should be discussed.

Reply: The host metabasalts of the study area have an island arc affinity (Chakrabarti et al., 2006) and can be related to the accretion of EDC (Eastern Dharwar craton) and WDC (Western Dharwar craton) along the CSZ (Chitradurga Shear Zone). Unloading from a few kilometers to the surface might generate jointing in host rocks, however, we did not find any such field evidence to support this.

Line 427. please expand this point to clearly state that these fracture systems are coeval.

Reply: Necessary change has been made in the manuscript as suggested by the Reviewer.

Line 470. as in the above comment. How do you ascribe to vein formation the cluster? The cluster my be inherited by the existing fracture network at the time of vein emplacement.

Reply: We have separately analyzed each of the clusters as suggested by the Reviewer. In each case the respective fluid pressure conditions (Pf) have been evaluated.

The WSW (highest density cluster, Fig. 7c) ascribes to the NNW-SSE trending vein orientations (attaining the maximum thickness). The NE and the SE clusters (refer to supplementary sheet-3) can be related to the vein orientations emplaced along the R and X shear fractures respectively (see figure 10).

Lines 474-476. As discussed above. Angular fragments of hosting rock within veins indicate hydrofracture with rupture of wall rocks. This is not directly associated with fault-valve action. Moreover, it is not clear if indications of hydrofracturing are observed in all vein sets or only in the NNW-SSE set. To clearly define a fault-valve action a look at the vein microfabric (crack and seal textures) will help.

Reply: This point has been addressed in Issue-1 (response to the main issues) discussed above.

Figure 1. Add definition of TTG and Supracrustals in the key legend. Figure 6. label (c) is poor-ly visible. Figure 10. The stress field in (c) has s1 vertical while the cartoon has ESE-WNW con-traction (yellow arrows). If fluid overpressure acted this should put into the figure caption.

Reply: All the suggested corrections in Figures. 1, 6 and 10 have been incorporated in the main manuscript.

Apart from the above, the reviewer suggested a few minor corrections in the annotated manuscript (pdf), which has been addressed in the revised manuscript.

With the above revisions I hope that all the questions raised by the Reviewer have been addressed.

Thanking you,

Sincerely yours,

Tridib Kumar Mondal

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Supplementary sheet 2

(a) Field photograph of metabasalt, hosting quartz veins with multiple median lines. (b) Field photograph of quartz vein (close view) showing multiple median lines (marked with red arrows) as an evidence of crack-seal mechanism. This clearly indicates cyclic fluid ingression and fault valve action that led to the formation of veins in the metabasalts of the Chitradurga region.

Fig. 1. Supplementary 2

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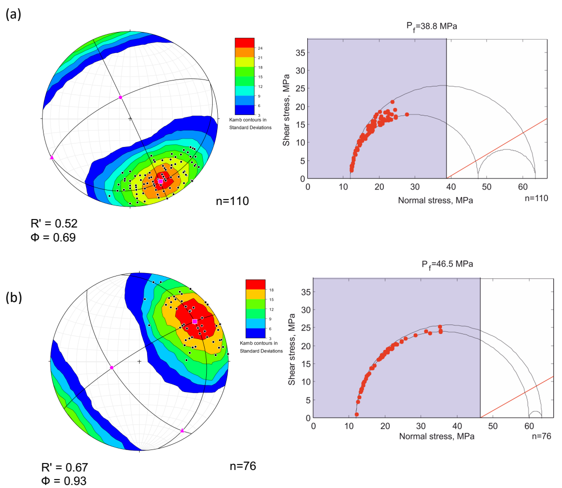
Discussion paper

Supplementary sheet 3



State of stress and fluid pressure (P_f) conditions determined from the vein orientation data in the study area. (a) Lower hemisphere equal area projection of poles to vein data forming the SE cluster along with the 3D Mohr circle diagram for low P_f condition. (b) Lower hemisphere equal area projection of poles to vein data forming the NE cluster along with the 3D Mohr circle diagram for low P_f condition. In the respective lower hemisphere equal area projections, cluster distribution of vein pole data indicates $P_f < \sigma_2$. Cluster maxima defines σ_3 axis. The ranges of fracture orientations (θ) are measured. Subsequently, ϕ and R' values are also determined similar to Fig 7, a and c. We found that data recorded from the SE and the NE clusters are greater in number as compared to the WSW cluster in Fig 7c. However, these data (of SE and NE clusters) show greater spreading as compared to the high-density clustering of data in Fig. 7c (WSW cluster). Color scheme of the legends indicate variation in the contour density. Pink circle (σ_1), pink triangle (σ_2) and pink square (σ_3) respectively. In the 3D Mohr circle diagrams, only a limited range of fracture filled up with veins are susceptible to reactivate. Red dots represent pole to vein data, red line forms the reactivation envelope for cohesionless fractures. Vein pole data lying within the blue zone, i.e., to the left of the P_f (black) line represent fractures filled up with veins that are susceptible to reactivate.

Fig. 2. Supplementary 3