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Solid Earth
Discussions

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

Sreyashi Bhowmick and Tridib Kumar Mondal

tridibkumarmondal@gmail.com

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We thank the reviewer for the valuable and constructive comments on the manuscript. We believe that the comments have made us think more deeply and have helped in revising the manuscript considerably. The reviewer has mentioned two issues regarding the manuscript. We have implemented, most of the changes suggested and addressed some of his points in details, below. In other cases, we clarified our arguments.

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Discussion paper

Issue: 1

The reviewer has raised his first concern regarding the quantification of sigma 3 and mentioned "In page 14 (lines 273-274), it is mentioned: "Tensile strength of metabasalt (_12 MPa; obtained from BTS studies) indicates that the minimum principal stress (sigma3) has to be sigma3 _ 12 MPa." Thereafter, this value is selected as magnitude for the minimum principal stress for the stress reconstructions (e.g. Fig. 7). I am particularly puzzled by the reasoning. The condition for tensile fracturing is sigma3 – pore pressure less or equal to the negative value of tensile strength. That is if sigma3 = 12 MPa then Pf has to be equal or higher than 24 MPa... Starting from there could the authors explain how they constrain sigma3?"

Reply:

We would like to thank the reviewer for addressing this issue. The tensile strength of metabasalt was obtained from BTS studies which was further used to denote the magnitude of the minimum principle stress ($\sigma 3$). Here we explain the rationale behind this assumption. It is interpreted that the tectonic stress was more dominant during the initial fracturing, which was followed by episodic fluid pressure pulses leading to fracture reactivation and vein emplacement. The 3D Mohr circle diagrams in Fig.7 and Fig.8 (of the revised manuscript), represents the relative fluid pressure conditions only. We have provided the effective normal stress conditions separately in Fig. 11 (Schematic model in the revised manuscript). However, in order to address the Reviewers concern for $\sigma 3$=12 MPa, we have added a few sentences in the main manuscript justifying the reason behind such a consideration. It definitely enhanced the quality of the manuscript. The magnitude of $\sigma 3$ can also be estimated using the stress intensity factor (fracture toughness), KIC. KIC for mode-I fractures, can be determined using the following equation (Lawn and Wilshaw, 1975; Atikinson, 1989). KIC = $\sigma 3 Y(\pi a)1/2$, where $\sigma 3$ is the minimum far field stress acting normal to the crack, Y is a numerical modification factor to account for the crack geometry and edge effect, and 'a' is the crack half-length. Microstructural investigation suggests that the metabasalts are generally fine to medium grained, massive and consists of plagioclase laths and altered pyroxene with minor chlorite, ankerite and quartz (Gupta et al., 2014). Within the metabasalts, variably oriented larger phenocryst grains range from 2 mm to 8 mm in length. It is evident that the large phenocrysts were more susceptible to generate the initial fractures as compared to the medium to fine grained groundmass in these types of rocks. Therefore, we have considered that the length of the initial crack ranges from 2 mm to 8 mm (Brace, 1964). KIC value for the metabasalts are found to be 1.069 (Donovan, 2003). Considering this KIC value and the range for fracture half-length (a), the σ3Y value for the metabasalt ranges between 9-19 MPa. From this strength range we considered that 12 MPa is a reasonable estimate for the in situ tensile strength (similar to the laboratory strength) of the corresponding lithology. It may also be noted that, previous studies by Mondal and Acharyya, 2018, conducted in Chitradurga Granite, in close vicinity of the study area also regarded the magnitude of $\sigma 3 \sim 10$ MPa, to be a good estimation. Combining these estimations with the results obtained from the present studies, we constrained the value for $\sigma 3 \sim$12MPa.

Issue: 2

The reviewer has raised his second concern regarding the Pf condition and mentioned "It is proposed that the veins formed in response to various fluid pressure pulses (see pages 13 and 14, and Fig. 7), which is reasonable and supported by numerous studies (e.g. discussion in Yamaji et al. 2010, p. 1139). The analysis suggests two extreme values for the fluid pressure: a maximum Pf derived from the Bingham distribution of all the measured veins and a minimum Pf, corresponding to the Bingham distribution of a selected subset of veins forming an elliptical cluster around sigma3 (see Fig. 7). It is totally unclear how the authors have selected the subset indicating, presumably, the actual minimum pore pressure. For example if one decides to select another subset of poles forming a tighter cluster around sigma3, Pf will be further reduced. It is just a mathematical consequence (see Jolly and Sanderson 1997)... In addition, stress anisotropy is theoretically insensitive to pore pressure variations. Surprisingly, the two inversions shown in Fig. 7 indicate rather different shape values, though pore pressure is the only quantity that is expected to change. In conclusion, the results themselves suggest that the selection of the subset of poles is merely subjective and the advanced minimum pore pressure value badly supported by the analysis".

Reply:

We would again thank the Reviewer for pointing out this problem. In Fig.7, we tried to quantify multiple fluid pressure pulses from the vein pole distribution data. Although, it is critical to differentiate various episodes of fluid ingression from a single large event. Initially we considered the girdle distribution of data points indicating, Pf > σ2 (Jolly and Sanderson, 1997; McKeagney et al., 2004; Mazzarini and Isola, 2007; Martinez-Poza et al., 2016). However, as the distribution of data points show three prominent clusters, we decided to extend our analysis to all the respective clusters and not only the WSW cluster (with highest cluster density). We have incorporated the analysis for the other two clusters as well (NE and SE clusters) in the revised manuscript, as also suggested by Reviewer-1 (see fig. 8 in the revised manuscript). The number of obtained clusters can also be testified through mixed Bingham analysis using K vs BIC (i.e., the number of Bingham component of a mixed Bingham distribution vs Bayesian information criterion; Yamaji and Sato, 2011). We have found that the lowest BIC values are obtained when K=3 (number of possible clusters for the given data set), thereby, justifying the selection of the three clusters for the analysis. In each case, Pf values for the respective clusters were obtained, which is most likely to differ, as mentioned by the Reviewer. It is absolutely true that if we select a tighter cluster, thereby reducing the contour interval, the Pf value will be further reduced. However, field evidences suggest that most of the vein orientations representing the WSW cluster show a NW-SE to NNW-SSE trend. Also, veins along this orientation attained maximum thickness along with multiple median lines. Thus, we decided to extend the contour interval beyond the data points in order to incorporate the maximum range of vein orientations (θ) lying parallel/sub-parallel to the internal anisotropy (as evident from the anisotropy of magnetic susceptibility study) of the host rock. Also, the contour interval and significance level for each of the clusters were selected in such a way that maximum number of data points are included, in order to obtain a statistically viable data cluster. It is however difficult to quantify the lowest Pf value; we therefore intend to use the obtained Pf values from the respective clusters as examples of low Pf conditions denoting Pf fluctuation rather than quantifying the lowest Pf condition of the study area. We have obtained different shape values (ÑĎ) for the inversions, this is because of the variation in the magnitude of $\sigma2$. Both magnitude and orientation of $\sigma2$ changes from high to low Pf conditions as explained by the k2/k1 ratio, regarded as the stress ratio (ÑĎ), which is expressed as k1 $\approx$ k2, for clustered distribution and k1 « k2, for girdle distribution (k1, k2 are the concentration parameters of a Bingham distribution; Yamaji, 2016). We hope this provides a better explanation for the interpretation of episodic fluid pressure condition prevailing in the region. In the revised manuscript we have added a number of lines in section 4.3, which increases the clarity of the manuscript.

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

Thanking you

Yours sincerely

Tridib Kumar Mondal (Corresponding author)

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