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Parametric and non-parametric methods of determining paleostress from dykes or veins

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Orientaions of dykes and veins are clues to ancient tectonic stress states. Newly formed open fractures in intact rock masses are expected to be perpendicular to the minimum compressive principal stress ($sigma_3$) axis. Jolly and Sanderson (1997) extended this concept for re-opening of pre-existing fractures. Their model allows us to infer orientations of three principal stress axes and stress ratio Phi=($sigma_2$-$sigma_3$)/($sigma_1$-$sigma_3$), and it provides a basis for the determination of stress magnitudes (Andre et al., 2001). The difficulty of this method is in the recognition of border of orientation range since the frequency of fractures gradually decreases toward the border in most cases. Yamaji et al. (2010) solved this problem by fitting the Bingham (exponential) distribution to the orientational frequency of fractures. This method need not specify the border of orientation range. The basic assumption of their method is the monotonous decrease of fracture frequency against the tectonic normal stress.

However, there can be a fracture distribution of which frequency decreases not exponentially. This study proposes two modified methods. One employs a shifted power type of stochastic model, which has a larger degree of freedom and can express various types of decreasing function flexibly. It should benoted that the shifted power model has an advantage in determining reletive value of fluid pressure lambda=(P_f-$sigma_3$)/($sigma_1$-$sigma_3$), where P_f is the fulid pressure. Another modified method is non-parametric and does not use a stochastic model. This method searches for an optimal stress state which minimizes the rank correlation coefficient between fracture freqnencies and normal stress magnitudes at all possible orientations. The advantage is in the exclusion of extra assumption on the type of orientation distribution.

For the purpose of testing the new methods, we analyzed simulated fracture datasets. Firstly, the three methods were applied to a simulated dataset obeying a Bingham distribution. As results, correct principal stress orientations and stress ratio were commonly obtained within confidence ranges. The precisions and accuracies of Bingham and shifted power models were equvalent and higher than those of non-parametric method. Secondly, a simulated dataset obeying stepwise distribution were analyzed to find that the shifted power model was superior to the other two methods in precision and accuracy. Consequently, the shifted power model generally performs well, while the non-parametric method is also useful with acceptable precision for its fewer assumptions.

We applied the methods to the Early Miocene andesitic dyke swarm intruded into Mino-Tamba Belt around Tsuruga city, Fukui Prefecture (Hoshi and Takagawa, 2009). The three methods commonly resulted in a normal-faulting stress regime with a NW-SE trending sigma_3 axis. The precisions of Bingham and non-parametric methods were similar, while that of shifted power method was superior to them. The type of frequency distribution of dykes was nearly linear, and a stress ratio of Phi=0.66+0.19/-0.22 and a relative fluid pressure of lambda=0.76+0.06/-0.16 were obtained. Although the shifted power model cannot deal with a complicated frequency distribution in comparison to non-parametric method, it is useful for the objective determination of relative fluid pressure which is an important parameter to investigate crustal dynamics.

References

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