Repeated stress state overturns during magmatic/hydrothermal fracturing in deep crust (Sør Rondane Mountains, East Antarctica)

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Stress state and fluid pressure are one of the most important parameters that govern crustal fracturing. Recent geophysical observations suggest that crustal seismic swarms are associated with migration of pressurized fluid, whose activities may link from deep tremors in lower crust (e.g., Yukutake et al., 2019). However, geological observations of such high fluid pressure, its duration, and stress sates in the crust are rather qualitative, and their relations to geophysical observations remain largely unconstrained. Exceptionally well-exposed crustal sections of Sør Rondane Mountains (SRM), East Antarctica provides an excellent opportunity to evaluate the fluid-assisted fracturing in the deep crust (e.g., Higashino et al., 2013; Mindaleva et al., 2020). Here we show paleostress and fluid pressure inversions of hydro-fractured metamorphic complex, utilizing 3D aerophotography images. Combined with constraints on the duration of fluid activities, we show geologic records of dynamic stress state overturns during magmatic/hydrothermal fracturing.

The study area is located at high-temperature metamorphic terrain, Sør Rondane Mountains, East Antarctica. Granulite-facies felsic gneiss (OFG) are cut by fractures filled with granitic veins, and biotite and amphibole veins (m to ~100 m in length; Fig. 1a). Brownish OFG are hydrated along the fractures and form whitish reaction zones composed of amphibolite-facies felsic gneiss (HBG), characterizing magmatic/hydrothermal fluid infiltration at 0.40–0.55 GPa, 600–670°C.

The whole outcrop of OFG (120 m ×70 m ×80 m) was photographed by an unmanned aerial vehicle (UAV; i.e., drone). 32 aerophotography images were processed with a commercial photogrammetric software program (Agisoft Metashape Pro) to generate a 3D digital model of the outcrop (Fig. 1a). The strike and dip of the 190 fractures were measured by a conventional 3D processing software (Fig. 1b). The datasets of fracture orientations were further analyzed for paleostress inversion using GArcmB software (Yamaji, 2016).

The fractures largely orient NE–SW and NW–SE in strike, and dip steeply towards SE and SW, respectively (Fig. 1c). The results of fracture clustering indicate 2 or 3 clusters are appropriate, based on the Bayesian information criterion (BIC; Fig. 1e). The results assuming 2 clusters suggest that fractures are largely classified into a group with NE–SW strike (cluster 1) and one with NW–SE strike (cluster 2) (Fig. 1d). Cluster 1 is characterized by NE subhorizontal σ_1 (dip direction/dip: 59°/5°), SE subvertical σ_2 (157°/60°) and NW oblique σ_3 (326°/30°). Cluster 2 is characterized by NW oblique σ_1 (335°/23°), SE subvertical σ_2 (205°/57°) and ENE oblique σ_3 (75°/23°). The stress ratios $(\sigma_2 - \sigma_3)/(\sigma_1 - \sigma_3)$ for both clusters are ~0.50. The normalized fluid pressure $p = (p_f - \sigma_3)/(\sigma_1 - \sigma_3)$ were inferred as $p <$~0.4 and <~0.5 for the two clusters (Fig 1f).

The above results indicate that the observed fractures are formed mainly under two different stress states. While the orientations of the σ_2 are almost identical among the two stress states, those of σ_1 and σ_3 switches between the two states (Fig. 1d). Fractures filled with granitic veins and biotite and amphibole veins were observed for both clusters (Fig. 1b), indicating that both clusters were associated with magmatic and hydrothermal activities. Outcrop observation indicates that the fractures belonging to the two clusters crosscut each other. Previous petrological analyses had shown that fluid activity during the formation of individual biotite-amphibole vein is geologically short, and is on the order of ~hours (Mindaleva et al., 2020; Uno et al., 2021 JpGU abstract). These results suggest that local stress states had repeatedly switched during the hydrofracturing associated with magmatic intrusion in the middle-lower

crust.

Such local stress switching could be analogous to those observed under active volcanos, that are mainly explained by fluctuations of fluid pressures (e.g., Miller et al. 2010). Although stress switching in the active volcanos are often reported in shallow crust, our observation suggests that stress overturns would also occur in middle crustal conditions near magmatic chambers (i.e., ~20 km in depth).

References

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