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Crustal fluid pressure gradients and permeability evolutions estimated from metamorphic fluid-rock reaction zones (Sør Rondane Mountains, East Antarctica)

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Fluid activity in the crust is a key process controlling the generations of earthquakes, magmas, ore deposition formation and deep geothermal activities. Although high pore fluid pressure has been recognized by geophysical observations and geological observations of mineral filled fractures, the actual fluid pressure, their durations and associated permeability are controversial and remain largely unknown. Here we propose a new methodology estimating the duration, fluid pressure gradients and permeability recorded in fluid-rock reaction zones, by utilizing thermodynamic analyses in conjunction with halogen (Cl, F) profiles along the reaction zones.

We have analyzed exceptionally well-exposed crustal fluid–rock reaction zones at Sør Rodane mountains, East Antarctica. The thermodynamic analyses of granitic dike–granulite-facies crust reaction zone at 0.5 GPa, 700°C (Uno et al., 2017) and amphibolite-facies hydration reaction zones around mineral-filled fractures at ~0.3 GPa, 450°C (Mindaleva et al., 2020) reveals extremely high fluid pressure gradients of ~100 MPa/10cm or ~1 MPa/mm across the reaction zones. The reactive transport analysis suggest that fluid activity lasted for 100–250 days and ~10 hours, respectively. These extremely high fluid pressure gradients represent the low permeability of the intact amphibolite and granulite host rocks without fractures. The estimated permeabilities of the host rocks are 10^{-20}–10^{-22} m^2, and are several orders smaller than the widely accepted crustal permeability model (~10^{-18} m^2; e.g., Ingebritsen and Manning, 2010). On the other hand, permeability along the fractures are estimated as high as 10^{-11}–10^{-16} m^2, which is analogous to the permeability estimated for the hypocenter migration for the crustal earthquake swarms (~$10^{-14\text{–}15}$ m^2; e.g., Nakajima and Uchida, 2018). Our observation supports that low permeability of intact crust promotes fluid accumulation and subsequent fracturing in the crust and/or underlying plate boundaries.

[References]

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