Physical conditions of magmatic–hydrothermal fracturing in the deep crust: possible geological records of subvolcanic deep low-frequency earthquakes

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Subvolcanic regions are among the most active seismogenic zones in arc crusts[e.g., 1]. Recent geophysical observations have revealed that deep low-frequency earthquakes (DLFEs) in the lower crust are coupled with volcanic earthquakes in the upper crust, suggesting that magmatic or hydrothermal fluid flow triggers these earthquakes[2,3]. Such crustal fracturing and dynamic fluid flow are likely to be recorded in high-temperature metamorphic terranes. Here we show occurrences of magmatic dikes and hydrothermal mineral veins in a high-temperature metamorphic terrane[4–6], characterize their fracturing modes, duration of fluid flow, stress state, and fluid pressure during activity, and discuss their relation to the observed seismic activity.
The study area is a high-temperature metamorphic terrane of Sør Rondane Mountains, East Antarctica. The metamorphic terrain was formed by the collision of the east and west Gondawana, while its P-T conditions are analogous to arc crusts. High-angle granitic dikes and/or hornblende±biotite veins commonly occur throughout the survey area. The dikes and veins cut the local gneissosity with extensional or extensional-shear displacements, intrude into the granulite-facies rocks, and form hydrous reaction zones along the dikes and/or veins. Reaction zones are characterized by the replacement of the pyroxenes with amphibole and biotite/phlogopite, representing hydration reactions at 600–750˚C and ˜0.5 GPa to 0.6–0.8 GPa (i.e., 20–30 km depth).
Within the reaction zones, Cl and F concentrations in apatite, biotite, and/or amphibole are highest within the dikes or veins and decrease toward the host rock. Reactive-transport modeling of Cl and F suggests advection-dominated transport (Péclet number ≫ 10) and fluid activity lasting days to months for dikes and hours to weeks for veins.
Thermodynamic analyses of the reaction zones indicate that the fluid-pressure gradient from the dikes to the host rock was ˜10 MPa cm^{-1} during dike/vein formation. Combined with the estimated duration of fluid activity, the maximum duration of high fluid-pressure conditions was likely days to months (dikes) and hours to weeks (veins).
Orientations of the granitic dikes and veins vary in outcrops near a magma chamber but remain relatively constant in outcrops far from the magma chambers, suggesting stress-state switching in the former and a stable stress state in the latter. These variations appear related to distance from magmatic chambers and likely reflect differences in magmatic fluid pressure.
The dikes typically have widths of 1–20 cm, lengths of 1–200 m, and shear displacements of 1–30 cm, while thicker dikes usually show multiple intrusions of 5–20 cm widths, indicating moment magnitudes of Mw −1.5 to 3.5, mostly clustering at −1–2.
These observations suggest that the extensional and/or extensional shear fracturing is common during the movement of magmatic fluids in the middle-lower crust. Granitic dikes release excess aqueous fluid, elevate local fluid pressure for days to months, and subsequently form hornblende ±biotite veins within hours to weeks. The depth (20–30 km), temperature (˜700 ˚C), duration of high-pressure fluids (hours to months), extensional-shear fracturing, and magnitudes (-1 to 2) observed in these dikes and veins are

broadly comparable to those of subvolcanic DLFEs[e.g., 2,7]. The geological observations strongly support non-double-couple mechanisms for crustal fracturing in these regions. Repeated changes in the apparent P-axis of focal mechanisms likely reflect repeated intrusions of highly pressurized magma.

[References]

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