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Amount, composition, and generation timescale of magma produced by melting of lower crust

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Magmatisms are various in continental margins and continental hot spots. Magmas with various petrologic features erupt at a certain volcano and are also different from other neighbor volcanoes. For the variety of the continental magmatism, magma genesis by crustal melting can be a key process. In this study, we try to understand variation of composition, amount, and generation timescale of magmas produced by melting of a lower crust due to repeated injections of hot magmas using a one-dimensional physical model.

The model of crustal melting by Koyaguchi and Kaneko (2000) is followed. When a crust is melted by a hot magma injected into a crust, large heat flux from the convecting injected magma rapidly melts the overlying crust up to the degree of partial melting large enough to convect (~100 yr timescale). After that, the injected magma and convecting region of partially-molten crust decrease in temperature and melt fraction, and hence cease to convect for melt fraction to decrease down to the critical melt fraction where the mixture of solid and liquid cannot convect. At this stage, heat transfer becomes only conductive and slow (>10,000 yr). When a new injection of a hot magma occurs, the above processes repeat. A characteristic of our model is that voluminous crustal melt close to the critical melt fraction tends to be produced. Additionally, we consider that the injected hot magma is hydrous, and an effect of crust wet by the water supplied from them is taken into account.

We carried out calculations considering that gabbroic amphibolite with 2 wt. % water is melted by repeated injection of hot basaltic magmas with initial temperature of 1250 deg. C at 1 GPa. It is assumed that the critical melt fraction above which the materials are convective is 0.5. In the calculations, we change the initial temperature of the crust (500-700 deg. C) and injection rate (2-30 m/ky), thickness in a single injection (10-800 m), and water content (2-12 wt. %) of the injected hot magmas as parameters. It is assumed that the hot magmas repeatedly inject at the same level and that no segregation between melt and crystals occurs in our model.

The calculation results indicate that the generation of magma by crustal melting occurs on 10,000-year timescale and that various amounts of magma with various degrees of partial melting are generated by crustal melting for the four changed parameters. The injection rate of the hot magmas basically governs total melt amount produced by melting; larger injection rate produces larger amount of melt. On the other hand, the initial temperature of crust and the injection thickness of the hot magma affect the degree of partial melting of the crust. Thin intrusions in warm crust produces relatively much melt with small degree of partial melting (i.e. silicic melt) whereas thick intrusions in cold crust produces much melt close to the critical melt fraction (relatively large melt fraction) (i.e. mafic melt). The water content of the injected hot magmas gives a minor effect (lager water content tends to increase total amount of crustal melt and ratio of mafic melt amount).

The calculation results give many implications about composition, amount, and timescale in crustal melting. For example, magma generation timescale of 10,000 years is consistent with time interval of large silicic eruptions in some caldera volcanoes. Individuality of each volcano about composition and eruption amount of magma may be governed by the conditions in our model. Verification of our model with geological and petrological data of natural volcanoes is needed in future work.

Keywords: magma, crustal melting, large scale silicic magmatism, one dimensional physical model, water conent of mafic magma