Japan Geoscience Union Meeting 2011
(May 22-27 2011 at Makuhari, Chiba, Japan)

SVC048-09 Room:301B Time:May 22 11:45-12:00

One dimensional model on crustal melting by injections of hot magmas into continental crust

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Crustal melting by injection of hot magmas is an important process for magma genesis in continental crust. Most magmas in arc magmatism in continental crust like Japan are probably produced by crustal melting. An aim of this study is to understand constraints of composition, amount, and generation timescale of magmas generated by crustal melting due to hot magma injections. We report calculation results of an one-dimensional physical model on crustal melting where repeated injections of hot magmas into crust produce magmas.

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. It is considered that hot magmas repeatedly inject at the same level and that no segregation between liquid and crystal occurs in our model. Additionally, effects of water in the hot magma were also taken into account. The hydrous hot magma melts the crust, solidifies itself, becomes saturated in water, and releases free water into the overlying crust.

For calculation, the relationship between temperature, composition, and melt fraction of the crust was formulated on the basis of the melting experiments and MELTS program. We calculated melt amount and degree of partial melting for 300 ky in our model under constant initial conditions of initial temperature (1250 deg.C), composition except water (basaltic), and injection thickness (50 m) of injected hot magmas and temperature (0 deg.C of surface temperature and 20 deg.C/km of temperature gradient in the crust) and water concentration (2wt%) of the crust. Injection depth (0.25-1.0 GPas), the critical melt fraction of convection-nonconvection (0.5-1.0), injection rate (2-20 m3/m2ky) and water content (2-12 wt%) of the injected hot magma, and crustal composition (basaltic-dacitic) were varied as parameters in our calculations.

Important results of the calculations are as follows.

(1) Crustal melting efficiently proceeds by convection. Amount of crustal melt in convection case is more than 20 times to that in non-convection case.

(2) In convection case, the region that undergo convection by melting up to high degree of partial melting has mafic melt almost with the critical melt fraction for a long time after convection stops. Its overlying crust has silicic melt with low degree of partial melting.

(3) Injection rate of the hot magma is the most important parameter in this system. Larger injection rate increases amount of crustal melt. On crustal melt composition, amounts of mafic and silicic melts are comparative for 20-30 thousand years after beginning of the injection, but after that mafic melt becomes dominant. This temporal change of melt composition proceeds more rapidly in larger injection rate.

(4) Water content of the hot magma hardly affects amount and composition of melt, except for hot magma with extremely larger water content.

The above results is applied to the natural igneous system. Generation of comparative amount of mafic and silicic magmas in 20-30 thousand years after beginning of hot magma injection may present magmatism of large pyroclastic eruption cycles like Aso volcano which occur in 20-30 years interval. On the other hand, the situation that partial molten region with the critical melt fraction, which is porphyritic mafic magma, is dominant after 50 thousand years may be interpreted as porphyritic andesitic magmatism of magma in NE Japan.

Keywords: crustal melting, continental crust, physical model, heat transfer