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Lower crustal mush generation and evolution

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Recent seismic, field, and petrologic studies on several active and fossil volcanic settings provide important constraints on the time, volume, and melt fraction of their lower crustal magma bodies. However, these studies provide an incomplete picture of the time and length scales involved during their thermal and compositional evolution. What has been lacking is a thermal model that explains the temporal evolution and state of the lower crustal magma bodies during their growth. Here we use a two-dimensional thermal model and quantify the time and length scales involved in the long-term thermal and compositional evolution of the lower crustal mush regions underlying the Salton Sea Geothermal Field (USA), Mt St Helens (USA), and the Ivrea-Verbano Zone (North Italy). Although a number of seismic, tectonic, petrologic, and field studies explained the tectonic and magmatic evolution of these regions, controversy remains on their lower crustal heat sources, melt fraction, and origin of erupted magmas. Our thermal modeling results suggest that given a geologically reasonable range of basalt fluxes ($\sim 10^{-3}$ to 10^{-4} km3/yr), a long-lived ($>10^{5}$ yr) crystalline mush is formed in the lower crust. The state of the lower crustal mush is strongly influenced by the magma flux, crustal thickness, and water content of intruded basalt, giving an average melt fraction of <0.2 in thin crust with dry injections (Salton Sea Geothermal Field) and up to 0.4-0.5 in thicker crust with wet injections (Mt St Helens and Ivrea Zone). The melt in the lower crustal mush is mainly evolving through fractional crystallization of basalt with minor crustal assimilation in all regions, in agreement with isotopic studies. Quantification of the lower crustal mush regions is key to understanding the mass and heat balance in the crust, evolution of magma plumbing systems, and geothermal energy exploration.