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Making mushy magma chambers in the lower continental crust: Cold storage and compositional bimodality

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Increasing geological and geophysical evidence suggests that crustal magma reservoirs are normally low melt fraction ‘mushes’ rather than high melt fraction ‘magma chambers’. Yet high melt fractions must form within these mush reservoirs to explain the observed flow and eruption of low crystallinity magmas. In many models, crystallinity is linked directly to temperature, with higher temperature corresponding to lower crystallinity (higher melt fraction). However, increasing temperature yields less evolved (silicic) melt composition for a given starting material. If mobile, low crystallinity magmas require high temperature, it is difficult to explain how they can have evolved composition.

Here we use numerical modelling to show that reactive melt flow in a porous and permeable mush reservoir formed by the intrusion of numerous basaltic sills into the lower continental crust produces magma in high melt fraction (> 0.5) layers akin to conventional magma chambers. These magma-chamber-like layers contain evolved (silicic) melt compositions and form at low (close to solidus) temperatures near the top of the mush reservoir. Evolved magma is therefore kept in ‘cold storage’ at low temperature, but also at low crystallinity so the magma is mobile and can leave the mush reservoir. Buoyancy-driven reactive flow and accumulation of melt in the mush reservoir controls the temperature and composition of magma that can leave the reservoir.

The modelling also shows that processes in lower crustal mush reservoirs produce mobile magmas that contain melt of either silicic or mafic composition. Intermediate melt compositions are present but are not within mobile magmas. Silicic melt compositions are found at high melt fraction within the magma-chamber like layers near the top of the mush reservoir. Mafic melt compositions are found at high melt fraction within the cooling sills. Melt elsewhere in the reservoir has intermediate composition, but remains trapped in the reservoir because the local melt fraction is too low to form a mobile magma. The model results are consistent with geochemical data suggesting that lower crustal magma reservoirs supply silicic and mafic melts to arc volcanoes, but intermediate magmas are formed by mixing in shallower reservoirs.

We suggest here that lower crustal magma chambers primarily form in response to changes in bulk composition caused by melt migration and chemical reaction in a mush reservoir. This process is different to the conventional and widely applied models of magma chamber formation. Similar processes are likely to operate in shallow mush reservoirs, but will likely be further complicated by the presence of volatile phases, and mixing of different melt compositions sourced from deeper mush reservoirs.