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Granite formation and the continental crust: an experimental and field perspective on the key role of deep crustal fractionation

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A major question in Earth Sciences is how continental crust forms and how it is modified over geological timescales. Statistical geochemistry advocates for a secular evolution of granitoids from the Archean to the present. Several processes are constantly modifying the continental crust yet the initial formation of silicic crust is generally related to two hypotheses. One is melting of mafic or pelitic crust while the alternative is fractionation from primary mantle derived melts, but both processes may occur simultaneously. Volatiles and heat play a key role in determining the respective solidi of lower crustal rocks, with the important difference that volatiles available for partial melting processes are restricted to structural bound volatiles in hydrous phases, while crystallization produces a much larger variability of potential magmatic water contents. Here we present an experimental perspective on both melting and crystallization processes in the lower crust, with an emphasis on experimentally derived liquid lines of descent by fractional and equilibrium crystallization at middle to lower crustal levels for hydrous, calc-alkaline magmas. These results indicate that fractionation can explain some features of plutonic-volcanic systems that are commonly ascribed to partial melting. Experimental data at pressures of 0.7 to 1.5 GPa, simulating thin and thick lower continental crustal settings are compiled. The temperature ranged from near-liquidus conditions at 1300 - 1150 °C to near-solidus conditions at 700 °C. We investigate the mutual phase relations of the principal phases olivine, cpx, opx, garnet, amphibole, plagioclase and Fe-Ti-oxides. Crystallization experiments and field data demonstrate that liquids at 0.7 to 1.0 GPa evolve from metaluminous to slightly peraluminous, corundum normative compositions. We use new trace element partitioning data to model the trace element evolution of siliceous magmas. These data relax the necessity of generating large volumes of granitoids by melting of subducting plates as the major and trace element constraints can be satisfied by crystallization moderated lower crustal processes. If magmas in equilibrium with mantle peridotite are considered as the primary magmas from which lower crustal rocks form, crystallization produces between 40 and 70% of ultramafic, olivine, cpx and amphibole (±grt) dominated cumulates to obtain andesite to dacite compositions that are typical for more evolved upper crustal magmas and rocks such as tonalites and granodiorites. The cumulates will by recycled into the mantle creating a 'cumulate' cake, a variant of the 'marble cake' concept of Allegre and Turcotte (1986). At temperatures below 950°C fractionation of amphibole, plagioclase and Fe-Ti-oxide (hornblende gabbros) drives the SiO_2-content systematically from 53 to 78 wt% over a temperature interval of >250°C. The large temperature range of felsic liquids allows for a variety of processes such as recharge or assimilation, operating over a rather large time-scale (depending on local cooling rate). The fact that andesitic liquids with a liquidus temperature of 970°C at 7kbar will only crystallize 50% down to 730°, over a temperature interval of 250°C implies that such liquids can survive as mobile crystal mushes (< 50% crystals), in near thermal equilibrium between assimilation and recharge processes.