Impact of melt segregation on chemical composition with application to deep crustal hot zones

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The emplacement of mantle-derived basaltic sills in the mid- to lower crust can lead to the generation of large volumes of evolved melt in deep crustal hot zones (DCHZ). However, the few published models of heat and mass transfer in DCHZ which include melt segregation, describe phase change using simple melt fraction-temperature relationships. These fail to capture the impact of melt segregation on the chemical evolution of melt and residual solid. Motivated by this problem, we present a model of melting and buoyancy-driven melt segregation in a binary eutectic system in which phase fractions and compositions are explicitly described using a phase diagram. Melt segregation is assumed to occur along grain boundaries and local thermodynamic equilibrium is maintained. A 1-D column is modelled, with several different initial compositions and thermal boundary conditions.

We find that the porosity evolution of an initially homogenous column is similar to that predicted previously; however, melt migration causes the bulk composition to evolve towards the eutectic composition at the top of the column and towards the solid end-member at the base. In a heterogeneous column comprising two layers with initial compositions located on opposite sides of the eutectic, melt segregation leads to mixing of melt at the interface between the layers. Consequently, even though the temperature remains fixed, very large melt fractions with the eutectic (or close to eutectic) composition are generated. Our results show that melt segregation can have a significant and non-intuitive impact on melt and bulk composition, particularly in an initially heterogeneous source, which is not captured by models which omit melt segregation, or describe phase change during segregation using simple melt fraction-temperature curves. This has profound implications for our understanding of the processes that generate evolved magmas in DCHZ.

The influence of crustal composition on magmatic differentiation across five major crustal terranes

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The British-Irish Palaeocene Igneous Province (BPIP) is an ideal testing ground for the influence of crustal composition on ascending magmas as five major tectono-stratigraphic terranes are traversed on a transect from Skye in the North, to Carlingford in the South. These crustal blocks are bounded by major discontinuities, the Moine Thrust, the Great Glen Fault, the Highland Boundary Fault, the Southern Uplands Fault and the Iapetus Suture, and are isotopically extremely diverse. This led to the suggestion that ascending mantle-derived magmas may be variably contaminated by the terrane through which they pass (crustal provincialism, e.g. [1, 2]), but no comprehensive model has been presented so far. We have analysed over 200 samples for Sr, Nd and Pb isotopes in a spectrum of mafic to felsic igneous rocks from the central complexes of Rum (Hebridean Terrane), Ardnamurchan, Mull (Northern Highlands Terrane), Arran (Grampian and Midland Valley Terranes), Slieve Gullion and Carlingford (Southern Uplands Terrane). Together with previously published data and data from crustal lithologies (surface exposures and xenoliths), our results suggest that the local crust has been a significant influence on the majority of magma compositions at all of the complexes. The mantle Sr-isotope ratio (at 60Ma) for the region is suggested to be 0.7023–0.7032 [3, 4]. Our basaltic samples from throughout the province show a range of 0.7028 to 0.7111. Felsic rocks yield a range that shows further elevation (0.7066 – 0.7226), while crustal compositions span a range from 0.7065 to 0.7379. Therefore, a broad correlation between crustal terrane and the isotopic composition of BPIP igneous rocks does exist (crustal provincialism), implying that ascending magmas were significantly, and characteristically, modified by the crust through which they have travelled. Our data imply that only very primitive, and generally rare, high-MgO rocks are unequivocally suited for the extraction of sensible information on primary magmatic source(s). In turn, evolved mafic rocks frequently display lower crustal influences, while felsic rocks regularly record a more complex, multi-stage, evolution, reflecting the cumulative effects of successive fractionation and contamination events in deep and upper crustal reservoirs.

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