Role of density contrast on magmatic architecture in the Earth's crust

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Magma reservoirs probably grow incrementally by repeated sill-like intrusions. We investigate the conditions for repeated intrusions at the same crustal level by a feeder dike before a permanent molten reservoir can form. Sill inception requires that magma within a dike develop an overpressure that is large enough to overcome the strength of surrounding rocks. An efficient mechanism to achieve this involves ascent through layers with decreasing density, such that magma become negatively buoyant above some interface. Dike penetration through a succession of crustal layers with different densities was studied with a new numerical code. To significantly affect dike ascent, the density change in country rock must occur over a thickness of the order of the characteristic length-scale for the inflated nose region that develops below the dike tip. This characteristic length depends on the elastic properties of the host rocks, on magma buoyancy and on the flux of magma, and is typically around 1 km for basaltic magmas, which is of the same order of magnitude as the typical thickness of sedimentary strata and volcanic deposits.

A dike continues to rise even if magma becomes negatively buoyant above some interface due to the continuous input of new magma. In this case, it develops a swollen nose region that straddles the interface as the internal magma pressure builds up. Penetration characteristics and the magnitude of the magma overpressure are determined by a local buoyancy balance in the nose region, independently of the total buoyancy of the magma column between source and tip. For sill inception to occur, the thickness of the low density layers must exceed a threshold value which depends only on the rock strength and on the average negative buoyancy of magma independently of the magma flow rate. For basaltic melt, we estimate that this threshold thickness cannot be less than about 700 m and is 2 km on average. The overpressure that develops at the density inversion level is set by the vertical extent of the inflated dike nose region above that level, and hence is related to the volume of magma in that region. Thus, sill inception also requires that the total volume of magma available in an individual intrusion event exceeds a threshold value.