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Numerical models on shallow magma chamber formation

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A magma chamber can be defined as a body within the crust that is either partially or totally molten which is injected with new magma from a deep-seated reservoir. A shallow magma chamber acts as a sink as it receives magma from the deeper reservoir, and as a source for volcanic eruptions. Most shallow magma chambers appear to develop from sills, and some, such as many mid-ocean ridge magma chambers, maintain the sill geometry through their lifetimes. For a sill to function as a magma chamber, certain conditions must be met: (1) The sill thickness must be in the order of tens of metres. This thickness is reached by either a) when a complex of thinner sills amalgamates or b) magma accumulates due to multiple dyke arrests at the contact with the sill. (2) The sill must receive a fairly constant magma replenishment so the chamber remains partially or (more rarely) totally molten. Here, we present numerical models based on geophysical data on how an individual sill can evolve into a magma chamber. Sills generally exhibit a concave-upward or straight geometry, although they may take other forms e.g. stepped, saucer-shaped, or concave-downward. Seismic studies suggest that many shallow ocean-ridge magma chambers have a moderately smooth geometry (ellipsoidal) rather than an irregular network of dykes and sills. Our numerical results indicate as follows: Firstly, the deflection of dykes into sills is most favoured in the upper crust where there are many layers generating stress barriers/delaminations due to elastic mismatch, that is, contrasting mechanical properties. Secondly, a sill grows primarily by elastic-plastic deformation of the host rock in which it is emplaced, while host rock anatexis/stoping may generate space for some large sills. The elastic-plastic expansion is partly reflected in upward bending of the overburden and partly in downward bending of the underburden. Thirdly, while the initial sill stays liquid or 'soft', subsequent dyke injections become arrested at the contact with the sill and their magmas become partly absorbed into the sill, which thereby grows. Fourthly, the sill must remain totally or at least partially molten, which requires a high injection rate of dykes feeding the sills to have a chance of developing into a shallow magma chamber. A high dyke injection rate is most likely to be reached at high extension rates, such as at fast-spreading ridges. This may be one reason for the common sill-like magma chambers being located at fast-spreading ridges.