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The emplacement depth of sills and larger magma bodies: what are the physical controls and how are emplacement depths determined?

T. Menand

Department of Earth Sciences, University of Bristol, UK

(T.Menand@bristol.ac.uk / Phone: +44-117-9545243)

The formation and growth of magma bodies is both a mechanical and a thermal problem. Mechanically, the emplacement and development of an igneous body require the stalling of magma on its way to the surface. Furthermore, this storage of magma needs to be accommodated at rates that are compatible with lithospheric strain rates, a problem which becomes particularly acute when considering the magma volumes of large plutons and batholiths. Thermally, the existence of an active igneous body requires that heat and mass are transferred into this system at rates that are high enough to prevent the solidification of this body. Thus critical parameters are the rate of magma accumulation (i.e., the magma supply rate) as well as the local geotherm. Both these mechanical and thermal aspects of the formation and growth of magma bodies raise the issue of the depth or crustal level at which magma can stall and accumulate to ultimately form larger igneous bodies. Increasingly, these mechanical and thermal considerations combined with field and geochronological data suggest that plutons grow by the amalgamation of successive, discrete pulses, and that in many cases these magma pulses take the form of sills. Sills would thus represent the building blocks of larger plutons.

It has been shown recently that the emplacement of sills can be controlled by crustal rigidity anisotropy. In this case, sills form when their feeder encounters an interface separating a relatively compliant, yet elastic, strata overlaid by a comparatively more rigid strata. Sills formation is also affected by rotation of the local stress field, with sills

forming when the least compressive stress becomes vertical and thus being favoured in compressive tectonic environments. These two different controls on sill formation, however, do not necessarily operate on the same length scale. The rigidity-contrast control requires not only the presence of layers with different mechanical properties but also necessitates interfaces separating more competent layers overlaying less rigid ones; the length-scale associated with the presence of these specific interfaces is thus what determines the depth at which rigidity-controlled sills will form. In contrast, stress rotation can occur in homogeneous as well as heterogeneous solids. In the case of homogeneous solids, the depth at which sills form is determined by a balance between the horizontal most compressive stress, which favours the formation of sills, and magma buoyancy, which drives magma vertically and thus opposes sill formation. This competition between compressive stress and buoyancy determines the length scale over which stress-controlled sill formation occurs. Ultimately, the depth at which a sill forms depends on whether rigidity anisotropy or stress rotation is the dominant control, i.e. which of the anisotropy-controlled or stress-controlled length scales is the smallest.