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Initiation of rift-zone crustal magma chambers through the deflection of dykes into sills at layer contacts

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Along many rift-zone segments, magma is supplied to eruptions through dykes that originate at the crust-mantle boundary. Such segments do not develop crustal magma chambers. This is understandable since the general regional rift-zone stress field favours dykes. More specifically, in a rift zone the minimum principal compressive stress is normally horizontal and perpendicular to the zone. Most sheet intrusions are extension fractures, so that they tend to be perpendicular to the minimum compressive stress and thus vertical, that is, dykes. The regional stress field at divergent plate boundaries is thus not favourable to the formation of shallow magma chambers. Nevertheless, many rift zones contain composite volcanoes (central volcanoes), most of which are supplied with magma from shallow crustal magma chambers. Volcanotectonic studies of eroded rift zones, such as in Iceland, as well as geophysical studies indicate that many shallow magma chambers evolve from sills. Here I provide field descriptions of sills and extinct crustal magma chambers in the Quaternary and Tertiary palaeorift zones of Iceland. I propose three related conditions for the deflection of dykes into sills, and thus the potential initiation of a crustal magma chamber, namely: (1) Cook-Gordon debounding (delamination), (2) stress barriers, and (3) favourable material-toughness ratios due to elastic mismatch (difference in Young's moduli or stiffnesses of layers in contact). In the Cook-Gordon debounding, a weak contact opens up as a result of dyke-induced tensile stress. This condition is likely to be commonly satisfied at very shallow depths, as is supported by field observations and numerical models. A stress barrier is a layer where the local stress is unfavourable to a particular type of rock fracture, here a dyke. Field observations and numerical models show that on meeting a stress barrier, a dyke either changes into a sill or becomes arrested. As regards the material-toughness conditions, when the upper layer at a contact has the same or lower stiffness than the lower layer (hosting the dyke), there is little tendency for the dyke to become deflected into the contact. However, when the upper layer is stiffer, such as when a stiff basaltic lava flow is on the top of a soft pyroclastic layer, the dyke tends to become deflected into the contact to form a sill. Field results suggest that all these conditions may be satisfied simultaneously and cause dyke deflection into sills, particularly where the rock consists of alternating soft and stiff layers. Since the Quaternary lava pile in Iceland has many more soft (hyaloclastite) layers than the Tertiary lava pile, these conditions were probably commonly satisfied and efficient in generating sills and, by implication, shallow magma chambers, during the Quaternary. This may be one reason why, in comparison with the Tertiary lava pile, the Quaternary lava pile contains so many sills and extinct (plutons) and active crustal magma chambers.