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Mechanical and thermal effects of sill emplacement in layered rocks

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The injection of a sill has both mechanical and thermal effects on the host rock. The thermal effects include heating of groundwater, so as to generate geothermal water. For sedimentary basins containing petroleum, its maturity may be much affected by the thermal effects of a sill or a complex of sills. The mechanical effects include down-bending of the layers beneath and up-bending of the layers above the sill. An injected sill normally also acts as a stress raiser, that is, it gives rise to stress concentration. While the sill is fluid, it acts as a magma-filled cavity that concentrates the stresses around it, but when solidified, the sill acts as an elastic inclusion or inhomogeneity which also modifies the stress around it. Fore layered rocks, such as a lava pile or a sedimentary basin, earlier numerical models indicate that the local stresses generated around sills, either as fluid or solid bodies, may result in fracture formation in layers far away from the sill itself. These fractures increase the permeability of those layers where, thereby, may act as reservoirs of geothermal water or oil and gas.
Here we present field data on sills (and dykes), as well as analytical and numerical models on three related mechanisms for dyke deflection into sills in layered rocks. The mechanisms are: (1) the Cook-Gordon debonding (delamination), (2) stress barriers, and (3) favourable material-toughness ratios attributable to elastic mismatch, that is, difference in Young's moduli or stiffnesses between mechanical layers in contact.
To improve our understanding of the effects of sills and sill complexes on fracture formation and permeability increase in the surrounding layers, we made many numerical models. The main results may be summarised as follows:
(1) The main stress concentration and fracture formation around a fluid sill, a magma body, is at its lateral ends, that is, at the vertexes (the points at which the major axis of an elliptical sill intersects the ellipse itself).
(2) If the vertexes of the sill are close to existing faults, the faults may be reactivated and opened. When a propagating tip of a sill meets a reopened fault, it may use the fault partly as a pathway to a higher (shallower) contact between layers in the basin where, again, the sill may propagate laterally along the contact. This is one reason for the well-known sill climbing or staircase geometry, and is also well known from other hydrofractures such as mineral veins.
(3) More commonly, however, the sill forms its own inclined fractures at its vertexes (in a way similar to that by which ring-dyke segments form). This happens particularly when the sill diameter is large compared with the sill depth below the surface.
(4) An overpressured sill not only generates fractures at its vertexes but also above and below the sill in some, mainly stiff (high Young's modulus) layers. The sill-induced stresses concentrate in the stiff layers which, thereby, may become highly fractured and serve as potential petroleum and gas reservoirs. Thus some sill-induced reservoirs may form far away, in particular at a considerable distance below, from the sill that generates them.