Finite element analysis of conduit wall rock stresses associated with steady flow models

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Conduit erosion (i.e. the permanent removal of wall-rock) modifies conduit geometry during eruptions and affects eruption dynamics. However, there has been very little modelling of conduit wall-rock failure and none coupling erosion and fluid dynamic models.

Finite element analysis is a powerful tool to elucidate the behaviour of the wall-rock during both dynamic and static loading and is capable of dealing with inherently non-linear and complex systems. Initial investigations using the FEA package Abaqus have focused on conduit wall-rock loading based on the pressure profiles determined by the steady 1-D explosive eruption dynamics models of Costa et al., 2009. Their models assume a 6000 m conduit linking the chamber (of variable pressure) to the vent with a cylindrical, dyke-like or hybrid (dike that transitions to a cylinder) geometry. The fluid pressures in their set of simulations range from +30MPa to -106MPa, with respect to lithostatic.

FE models loading the conduit walls with the stress from the simulated fluid pressures suggest significant wall-rock failure would occur for all geometries modelled. For example, the pressure profile for a cylindrical conduit in an elastic medium (Youngs modulus = 40 GPa, Poissons ratio = 0.25, and yield strength = 20 MPa) results in damaged volumes of 10^7 m^3. Damage is focused around, and particularly important in, areas of conduit underpressures, as this material will implode into the conduit; erosion of damaged overpressured areas requires a further mechanism to remove material (e.g. magmatic shear stress or particle collisions). The forecasted yielded volumes exceed that of the conduit by an order of magnitude, suggesting that significant wall-rock failure would inhibit the development of the modelled steady flow pressure profiles. FE analyses with a dyke-like geometry suggest that significant failure would be focused near the dyke tips. Results for a dyke underpressure of 50 MPa (properties as above) indicate yielded cross-sectional areas of hundreds of square meters. Due to the spatial relationship between this damaged material and the dyke, this material would not easily be removed, although increased permeability through damage could be important in promoting magma-water interaction.

The amount of damaged material strongly depends on the initial size of the conduit and the assumed rock rheology. For increasingly complicated, quasi-steady models coupling 1-D flow and evolving conduit geometry based on FE wall-rock failure, an elastic-plastic wall-rock rheology may be more appropriate. In the static loading done to date, adjusting the rheology from elastic to elastic-plastic increases the damaged volume by orders of magnitude.