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Dynamics of buoyant magma bodies in viscoelastic crust

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Two assumptions often invoked when interpreting geodetic observations of volcano deformation are that host rock around magma bodies behaves elastically, and that magma density is equal to the density of the host rock (gravity is ignored). In many cases these assumptions are inappropriate, in particular for magma bodies that reside deep in the crust below the regional brittle-ductile transition where ductile flow relaxes stresses imposed by magma accumulation over time scales similar to or shorter than inter-eruptive time periods. A revision of modelling approaches is needed to understand the dynamics of such magma bodies, including their assembly and subsequent magma extraction and eruption. The total upward force acting on a magma body of a density lower than that of a surrounding viscoelastic crust is found, according to Archimedes law, by considering the integrated body force due to gravity acting on the magma body minus the gravity force on the crustal material that the magma body has replaced. At the boundary of the magma body this upward directed body force is transferred to a surface force acting on the surrounding crust by the magma body. A simple numerical approach to implement this condition is to consider a buoyancy overpressure within a magma body, scaling with height above the deepest point of the magma body and the density difference between magma and host rock, multiplied by gravitational acceleration. This pressure is transferred to a surface force at the boundary, in a direction normal to it. Integration of it over the whole boundary of a magma body recovers the total force equal to that predicted by Archimedes law. Magma body failure is reached when: (i) a buoyant magma body becomes too thick, (ii) its density decreases through magma evolution, (iii) pressure due to influx of magma becomes too large, (iv) external stress forces failure, or (v) through a combination of these. Evaluation of the buoyancy effect suggests that it can become the dominant effect driving magma bodies towards failure, if magma bodies are on the order of 1 km thick and the effective tensile strength of the crust is few MPa. This should be considered when evaluating potential failure of magma bodies and eruption onset. We present a model considering these effects for the Bárðarbunga volcano in Iceland and its 2014-2015 caldera collapse, lateral diking and major effusive eruption, as well as preceding magma accumulation.