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Analogue modelling of magmatic intrusion during thrusting

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Magma should rise through the upper crust more readily in a context of horizontal extension, than it does in one of compression. Extension should provide vertical conduits for rising magma, whereas compression should close vertical fractures, maintaining magma at depth. Nevertheless, volcanoes are common at convergent margins, even if the tectonic setting is compressional.

To investigate how magma may rise through a shortening upper crust, we have done a series of experiments on scaled physical models. The model materials were cohesive powdered silica, representing brittle upper crust, and a vegetable oil, representing magma. The oil was liquid and of small viscosity at 30˚C, but solidified at room temperature. A moving piston shortened a rectangular model in a box, while molten oil was injected through a circular hole at the base. During injection, the internal pressure of the oil was monitored. After the oil had cooled and solidified, longitudinal cross sections were made through the model. These revealed a pattern of intrusions and thrust faults. In a typical experiment, where injection and shortening were synchronous, oil accumulated at the base of the model, forming a sill. A straight thrust fault initiated at the base of the piston and an arcuate thrust fault nucleated at the leading edge of the sill. Between the two thrusts, a non- deformed plateau glided on the sill. In some experiments, oil rose along the thrusts.

In each set of experiments, the rate of injection (D) and the piston velocity (Vp) were the independent variables. The observed lengths of the non-deformed plateau (Lp) and of the basal sill (Li) were in proportion to D and in inverse proportion to Vp. Moreover, both Lp and Li were in inverse proportion to the dimensionless ratio R, between rates of shortening and injection.

In most experiments, the oil pressure decreased as a function of reciprocal time. We infer an active emplacement of oil into hydraulic fractures. In other experiments, where intrusion and shortening interacted, the oil pressure decreased strongly when arcuate thrusts appeared, suggesting a more passive emplacement. We infer that uplift of the non-deformed plateau favoured the emplacement of oil at the base of the model.

More generally, we deduce that magmatic intrusion in the upper crust is dependent on tectonic context and that shortening and intrusion are interactive processes.