From dike to plug: critical physical transitions in the evolution of sustainable basaltic volcanism

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Basaltic volcanic eruptions commonly are characterized by three stages. In the upper few kilometers of the crust, magma rises in planar dikes, resulting in fissure eruptions when they intersect the surface. In some cases, the fissures may not feed significant eruptions and may quickly (within hours) die out. In other cases, magma continues to erupt and localizes into discrete vents, until the flow is sustained through a central vent, which is able to carry much greater volumes of magma to the surface. These types of eruptions have been well documented in places like Kilauea volcano in Hawaii and are inferred to have operated in ancient systems like Ship Rock, New Mexico. However, the physical processes governing the evolution of conduit geometry from dike-like to plug-like and the associated eruptive dynamics are poorly understood. Field evidence from Ship Rock provides insights we use to develop a framework for what processes may have caused the evolution of dikes into plugs. Ship Rock is a maar-type diatreme standing 600 m above the surrounding land surface, with minette dikes extending radially away. Systematic joint sets in the host rock (Mancos shale) adjacent to dike contacts and the presence of breccias along the margins of the dikes and around plugs suggests that brittle deformation and subsequent erosion of the host rock was primarily responsible for changing conduit geometry. Fracture orientations and petrographic analysis of the breccias have allowed us to construct a conceptual model for what style of deformation has taken place, the sequence of these deformational events, and the stress state that gave rise to this deformation. We hypothesize the following order of events: 1) dike-parallel fractures form in the host rock ahead of the propagating crack tip; 2) magma intrudes and solidifies at the contact and oxides and calcite fill in pore space in the adjacent host rock; 3) dike-perpendicular fractures form in the host rock; 4) solidified magma fractures and host rock partially fluidizes; 5) fractured magma is eroded by the flow of molten magma; 6) fractured host rock is eroded by the flow of molten magma. An analysis of the state of stress around a dike identifies the primary controls on the various styles of deformation. The stress state includes mechanical stresses from dike opening, thermoelastic stresses from heat transfer, and pore pressure increases from coupled heat transfer and groundwater flow. We present the field evidence for the conceptual model and preliminary results from the stress analysis. Ultimately, physics-based numerical models will be developed to test which physical mechanisms primarily control the evolution of fissure- to central- type eruptions, and under what conditions this transition is likely to take place.