Feedback relationships between magma properties and volcanic eruption dynamics

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Complex, non-linear feedback relationships between magma properties and volcanic eruption dynamics are revealed by numerical simulations of coupled magma chamber, volcanic conduit, and atmospheric dispersal dynamics. The numerical simulations solve the 2D transient compressible-to-incompressible, multiphase, homogeneous magma chamber and volcanic conduit dynamics, 1D steady, multiphase separated conduit flow dynamics, and 2D transient, multiphase, separated gas/pyroclast atmospheric dispersal dynamics. The thermodynamic and rheological properties accounted for by numerical simulations describe multicomponent gas-liquid equilibria and Newtonian to shear-dependent viscosities of the multiphase magmatic mixture, as a function of magma composition and phase distribution, and of local flow conditions. The occurrence of magma fragmentation, and the transition from liquid to gas continuum, is described in terms of the visco-elastic properties of sheared magma. Complete feedback between properties and processes is allowed in the numerical simulations, which solve the transport and constitutive equations closed by selected initial and boundary conditions. The numerical results highlight the often non-intuitive roles in the global eruption dynamics of changes in the composition and properties of the erupted magma. Lower magma viscosities are associated with a more rapid pressure drop in the volcanic conduit and magma chamber during the initial transient phase of an eruption, and with the onset of velocity and pressure oscillations in deep conduit regions close to the conduit inlet. Initially volatile-oversaturated magma chambers may result in lower gas phase volumes at a given time after eruption onset, depending on magma viscosity and total volatile distribution. A feedback relationship involving pressure drop, volatile exsolution, magma acceleration, magma viscosity, and friction forces is found to largely control the steady phases of volcanic conduit flow. Large changes of underground flow variable distributions are sometimes associated with only minor modifications of the sub-aerial eruptive style, while in other cases minor compositional changes can produce significant variations and result in convective/collapsing transitions of the eruptive column.

Laboratory investigations into the causes of explosive volcanic eruptions

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Scientists have long known that volcanic eruptions are powered by the release of magmatic gas, predominantly H_2O and CO_2. What is less widely recognized is that it is not simply the amount of gas that determines the intensity of eruption, but also the depth and rate of its release. High temperature and pressure degassing experiments reveal that these three factors–amount, depth, and rate of gas release–are intimately tied to the thermodynamics and kinetics of gas bubble nucleation [1]. The activation energy involved in creating a bubble is supplied by the volatile supersaturation pressure. The required degree of supersaturation varies as a function of melt-vapor surface tension, and the extent to which crystals act as favorable nucleation sites.

Experiments with polymerized silicate melts show that surface tension varies with bulk composition and dissolved water [2]. The addition of H_2O and other network modifiers (MgO, FeO, CaO) lowers surface tension. The efficacy of crystal surfaces as nucleation sites also depends on bulk composition, and on crystal type [3]. Crystals that are strongly wetted by the melt (e.g., feldspars) are ineffectual. Generally, when surface tension is high and the facility of crystals to support bubble nucleation is low, nucleation requires large supersaturation.

Experimental results combined with numerical conduit flow models show that the kinetics of bubble nucleation dictate whether volatiles exsolve early and deep under quasi-equilibrium conditions, or late and shallow at extreme supersaturation [4]. Delayed bubble nucleation maximizes eruption intensity by limiting degassing to a rapid-fire burst over a narrow depth interval close to the surface.

References

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