A thermomechanical perspective on caldera formation and classification

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Decades of research have led to a mature understanding of caldera formation and evolution. In particular a temporal model for caldera formation (Smith and Bailey, 1968) is now well understood and morphological classifications based on geological studies (e.g. Lipman, 1997; Cole et al, 2005), recently informed by analogue models (Acocella, 2007), capture the final surface manifestations and styles of collapse and inferred relationships to chamber depth, size, and shapes (Lipman, 2000; Roche et al., 2000; Kennedy, 2000). However, our understanding of the processes that lead to these morphologies and the temporal evolution remain murky. In particular, what initiation and triggers catastrophic caldera collapse is unclear. The general two stage model of collapse (Stages 2 and 3 of Smith and Bailey, 1968) is the paradigm that prevails (Druitt and Sparks, 1984; Kennedy and Stix, 2003). In this model an initial eruption is triggered by overpressure in the magma chamber. Evacuation of magma and bleeding off the overpressure leads to an underpressured condition in the magma reservoir that triggers caldera collapse and pyroclastic flow generation. However, it has been increasingly recognized that many of the largest calderas do not conform to this two-stage model and involve catastrophic caldera collapse at the inception of eruption (Christiansen, 2005; de Silva et al., 2006). Moreover, many of these large calderas exhibit a significant structural resurgence that smaller systems do not. Large caldera collapses result in collapse of the entire upper crust above the magma system, smaller calderas form within the edifice. The details of the physical volcanology of the eruptions and the resulting ignimbrites are quite different.

These differences between large and small calderas can be understood from a thermomechancal perspective. Generation of viable large magma bodies requires elevated thermal fluxes and thermally mature crust (de Silva and Gosnold, 2007; Annen, 2009) that plays a fundamental role in the rheology of magma/host rock interface (Jellinek and DePaolo, 2003) and ultimately controls magma reservoir growth, pressure evolution, surface uplift, faulting, and caldera size (Gregg et al, 2012, 2013). In particular thermomechanical considerations suggest that in large systems the catastrophic caldera eruptions are "externally" triggered by mechanical failure of the roof. Smaller systems are "internally" triggered by overpressure within the magma reservoir. These different modes of triggering largely control the final form of the calderas and the character of the eruption and associated pyroclastic deposits. We suggest that catastrophic calderas can be fundamentally divided into two size divisions with an approximate boundary at 10km diameter, 100 km^3 and VEI=7. Ultimately this is a thermal or thermomechanical divide.

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