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# Erupting batholiths: shaken or stirred?

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Magma with a crystal fraction exceeding about 0.5 is generally perceived to be uneruptable due to its unfavorable rheology. However, there is irrefutable evidence in the geological history for the large-scale (>100 km3) eruption of crystal mush. We present field evidence from ignimbrites of caldera-forming eruptions related to the permo-carboniferous Prats d'Aguilo sequence (Spain), and the tertiary eruptions at Nazas, Sierra Madre Occidental (Mexico), Cerro Panizos volcanic centre (Central Andes), and the San Juan Volcanic field (USA), all of which document the eruption of seemingly uneruptable dacitic - rhyolitic crystal mush with crystallinities of between 0.45 and 0.6. Individual eruption volumes exceed 100 km3 of magma (dense rock equivalent) and thus document the evacuation of batholith-like reservoirs. The ignimbrites expose primary magmatic crystal contents in individual pumices and our inferences are thus not based on crystal concentrations in these deposits resulting from secondary enrichment processes. The deposits are characterized by crystal-rich, yet, low-vesicularity pumices, co-ignimbritic lag breccias and the absence of initial Plinian deposits, all of which indicating initial deep levels of fragmentation and lack of overpressurization at the initiation of the eruptions. These observations stand in clear contradiction to accepted models of eruption triggers whereby an eruption is fuelled by an increase in pressure due to gas exsolution in a supersaturated magma or due to chamber rejuvenation accompanied by volatile exsolution, bubble formation and finally melt fragmentation. Pyroclastic fragmentation will occur when the time to relax an applied mechanical stress (e.g. due to bubble growth) exceeds the characteristic relaxation time of the melt phase. This concepts certainly holds true for the majority

of volcanic eruptions. However, pumices from the case examples show low degrees of vesicularity ($<0.25$) and it is safe to propose that vesiculation-induced fragmentation was of second order, as quenched clasts from silicic magmas with melt viscosities higher than 1E9 Pas mirror the vesicularity of magma at the moment of fragmentation. While the above thermodynamic relationships still hold, an internal process such as in-situ vesiculation seems an unlikely trigger in our examples. An external trigger, however, could effectively drive a thermodynamically (meta-)stable system into catastrophic failure. We propose a combination of near-field seismicity due to normal faulting during active crustal extension and block subsidence as a possible trigger to the large-scale eruption of uneruptable crystal mush. This combination of effects results in a catastrophic perturbation of the magmatic system involving (i) deep-seated fragmentation at the magma chamber level (as evidenced by high abundance of plutonitic lithics in co-ignimbritic lag breccia), (ii) rapid decompression (as evidenced by large-scale evacuation of a pluton-like body), (iii) wide-spread ignimbrite deposition and (iv) roof collapse and onset of caldera formation. The combination of seismic stress changes and decompression may destabilize a pluton-like reservoir due to the incompatibility of timescales governing magma relaxation and stress accommodation. These conditions appear to be most favorably achieved in extensional “Basin and Range”-type tectonic settings.