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Experimental phase equilibria of hydrous felsic melts: Implications for magma storage and volcanic eruption

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Felsic magmatism has played a key role in continental crust formation and powers the most hazardous volcanic eruptions on Earth. Whether felsic magma reservoirs remain locked in the crust, intermittently produce small-volume eruptions, or erupt catastrophically is largely controlled by their internal physical state, particularly crystallinity evolution upon cooling, governed by phase saturation and equilibria. Despite nearly a century of experimental work, phase relations and melt fraction evolution at intermediate to high crystallinities remain incompletely known.

To address this, we performed crystallization experiments at 200 MPa on a fused representative sample of the calc-alkaline, medium-K Cathedral Peak Granodiorite of the late Cretaceous Tuolumne Intrusive Suite (Sierra Nevada batholith, USA). Experiments were conducted in externally heated Ar-pressurized Mo-HfC and H_2O-pressurized cold-seal vessels at XH_2O = 0.5 and 1.0, with fO_2 buffered by the Re + O_2 = ReO_2 equilibrium. Near-liquidus conditions (≥900°C) are characterized by crystallization of plagioclase, magnetite, and minor clinopyroxene, followed by a peritectic reaction in which clinopyroxene is consumed and amphibole forms at 875°C for XH_2O = 1 and 825°C for XH_2O = 0.5. Upon further cooling, amphibole, plagioclase, ilmenite, and magnetite dominate until a K-bearing phase saturates. At XH_2O = 1, a second peritectic reaction consumes amphibole,producing biotite and quartz, consistent with previous studies. At lower XH_2O, the same reaction consumes amphibole more gradually, whereas alkali feldspar saturates at ≤725°C.

These contrasting paths produce different crystallinity evolutions. At a given temperature, the low-XH_2O trajectory yields higher crystallinities, reflecting reduced melt fH_2O and the abrupt crystallinity increase associated with alkali feldspar saturation. Although high-XH_2O systems remain mobile to lower temperatures than low-XH_2O systems, the transition from mobile to immobile magma reservoir (45-60% crystallinity) systematically occurs at or below typical storage conditions (~700-750°C) for both systems. In contrast, slightly less evolved compositions are effectively locked at those temperatures. Consequently, rhyolitic magmas can remain mobile at storage conditions, permitting crystal-melt segregation and eruption with low crystal contents, whereas dacitic systems require additional processes to extract interstitial melt and tend to erupt crystal rich. This interpretation is consistent with the frequent eruption of crystal-rich dacites and, in some cases, crystal-poor rhyolites.