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New Ti-in-quartz diffusivities reconcile natural Ti zoning with time scales and temperatures of upper crustal magma reservoirs

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Time scales associated with magmatic processes are of primary interest for volcanic systems. The past decade has seen significant advances in this area through a combination of geochronology and geochronometry (Kent, 2015). The use of Ti relaxation times in quartz has received particular attention, especially in the study of high-silica rhyolites. Jollands et al. (2020) present new measurements for the diffusivity of Ti in quartz, which differ from the results of Cherniak et al. (2007) by more than two orders of magnitude, despite using similar experimental setups and conditions.

The Bishop Tuff record serves as a relevant testing ground of these diffusivities. Zircon crystallization spans ~100 ka prior to eruption, but most of that time represents a waxing and waning stage recorded primarily by zircon antecrysts (Simon and Reid, 2005; Chamberlain et al., 2014b). Quartz crystallization times are constrained to within centuries to a few millennia prior to eruption, suggesting that the magma bodies that fed the Bishop eruption were short-lived (Pamukçu et al., 2012, 2015; Gualda et al., 2012; Chamberlain et al., 2014a). The agreement between Ti relaxation times obtained using the Cherniak et al. (2007) diffusivities and melt inclusion faceting times obtained using Si diffusivity in the melt is striking (Gualda et al., 2012; Pamukçu et al., 2015), and strongly suggests that the Jollands et al. diffusivities are much too slow for these systems. Eutectic-like magmas like these would lose sufficient heat on centennial time scales to crystallize the 5–30 wt% crystals observed in pumice (Gualda et al., 2012); the diffusivities of Jollands et al. resurrect the problem of maintaining vast quantities of high-silica rhyolite magma in a melt-rich state for tens of thousands of years. Finally, short (<1 a) crystallization times inferred for crystallization of quartz rims and a microlite population observed in Bishop Tuff pumice is consistent with fast growth due to decompression (Pamukçu et al., 2012, 2016; Gualda and Sutton, 2016), a scenario that is also inconsistent with the Jollands et al. diffusivities.

The Oruanui Tuff is another useful example. Zircon compositions and ages constrain the longevity of Oruanui magmas to within 3 ka prior to eruption (Charlier et al., 2008). The centennial quartz crystallization times obtained using the Cherniak et al. (2007) diffusivities are consistent with this duration (Pamukçu et al. 2015, 2020) and are also confirmed by melt inclusion faceting times (Pamukçu et al. 2015), growth times from crystal size distributions (Pamukçu et al., 2020), and orthopyroxene Fe-Mg relaxation times (Allan et al., 2017).

Similarly, Shamloo and Till (2019) show rim growth times of quartz (by Ti relaxation) and sanidine (by Ba and Sr relaxation) in the Lava Creek Tuff that are in agreement with each other, as long as the Cherniak et al. (2007) diffusivities are used. Application of the Jollands et al. diffusivities to the results of Cooper and Kent (2014) for several relevant silicic systems would lead to quartz residence times longer than those inferred from plagioclase U-series disequilibria ages. Similar arguments can be made using the data from Flaherty et al. (2018) at Santorini.

All in all, we do not find support for the time scales determined using the diffusion coefficients of Jollands et al.. The fact that the experiments are newer does not inherently make them better, more accurate, or more reliable. The Jollands et al. (2020) diffusivities lead to results that are inconsistent with time scales determined using—at a minimum—Si diffusivities in rhyolites, Fe-Mg exchange diffusivities in orthopyroxene, Ba and Sr diffusivities in sanidine, U-Pb age dating of zircon, U-series dating of plagioclase, and thermal diffusivities of magmas. More experiments are critical to clarify this discrepancy. As it stands, the weight of the geological evidence strongly suggests storage and crystallization of eruptible high-silica rhyolites over centennial to millennial time scales, consistent with Ti diffusivities in quartz similar to those determined by Cherniak et al. (2007).

REFERENCES CITED

Allan, A.S.R., Barker, S.J., Millet, M.A., Morgan, D.J., Rooyakkers, S.M., Schipper, C.I., and Wilson, C.J.N., 2017, A cascade of magmatic events during the assembly and eruption of a super-sized magma body: Contributions to Mineralogy and Petrology, v. 172, https://doi.org/10.1007/s00410-017-1367-8.

Chamberlain, K., Morgan, D., and Wilson, C., 2014a, Timescales of mixing and mobilisation in the Bishop Tuff magma body: Perspectives from diffusion chronometry: Contributions to Mineralogy and Petrology, v. 168, https://doi.org/10.1007/s00410-014-1034-2.

Chamberlain, K., Wilson, C., Wooden, J., Charlier, B., and Ireland, T., 2014b, New perspectives on the Bishop Tuff from zircon textures, ages and trace elements: Journal of Petrology, v. 55, p. 395–426, https://doi.org/10.1093/petrology/egt072.

Charlier, B.L.A., Wilson, C.J.N., and Davidson, J.P., 2008, Rapid open-system assembly of a large silicic magma body: Time-resolved evidence from cored plagioclase crystals in the Oruanui eruption deposits, New Zealand: Contributions to Mineralogy and Petrology, v. 156, p. 799–813, https://doi.org/10.1007/s00410-008-0316-y.

Cherniak, D.J., Watson, E.B., and Wark, D.A., 2007, Ti diffusion in quartz: Chemical Geology, v. 236, p. 65–74, https://doi.org/10.1016/j.chemgeo.2006.09.001.

Cooper, K.M., and Kent, A.J.R., 2014, Rapid remobilization of magmatic crystals kept in cold storage: Nature, v. 506, p. 480–483, https://doi.org/10.1038/nature12991.

Flaherty, T., Druitt, T.H., Tuffen, H., Higgins, M.D., Costa, F., and Cadoux, A., 2018, Multiple timescale constraints for high-flux magma chamber assembly prior to the Late Bronze Age eruption of Santorini (Greece): Contributions to Mineralogy and Petrology, v. 173, p. 75, https://doi.org/10.1007/s00410-018-1490-1.

Gualda, G.A.R., Pamukçu, A.S., Ghiorso, M.S., Anderson, A.T., Jr., Sutton, S.R., and Rivers, M.L., 2012, Timescales of quartz crystallization and the longevity of the Bishop giant magma body: PLoS One, v. 7, https://doi.org/10.1371/journal.pone.0037492.

Gualda, G.A.R., and Sutton, S.R., 2016, The year leading to a supereruption: PLoS One, v. 11, https://doi.org/10.1371/journal.pone.0159200.

Jollands, M.C., Bloch, E., and Müntener, O., 2020, New Ti-in-quartz diffusivities reconcile natural Ti zoning with time scales and temperatures of upper crustal magma reservoirs: Geology, v. 48, p. 654–657, https://doi.org/10.1130/G47238.1.

Kent, A., 2015, Tackling supervolcanoes: Big and fast?: Geology, v. 43, p. 1039–1040, https://doi.org/10.1130/focus112015.1.

Pamukçu, A.S., Gualda, G.A.R., and Anderson, A.T., Jr., 2012, Crystallization stages of the Bishop Tuff magma body recorded in crystal textures in pumice clasts: Journal of Petrology, v. 53, p. 589–609, https://doi.org/10.1093/petrology/egr072.

Pamukçu, A.S., Ghiorso, M.S., and Gualda, G.A.R., 2016, High-Ti, bright-CL rims in volcanic quartz: A result of very rapid growth: Contributions to Mineralogy and Petrology, v. 171, https://doi.org/10.1007/s00410-016-1317-x.

Pamukçu, A.S., Gualda, G.A.R., Begue, F., and Gravley, D.M., 2015, Melt inclusion shapes: Timekeepers of short-lived giant magma bodies: Geology, v. 43, p. 947–950, https://doi.org/10.1130/G37021.1.

Pamukçu, A.S., Wright, K.A., Gualda, G.A.R., and Gravley, D., 2020, Magma residence and eruption at the Taupo Volcanic Center (Taupo Volcanic Zone, New Zealand): Insights from rhyolite-MELTS geobarometry, diffusion chronometry, and crystal textures: Contributions to Mineralogy and Petrology, v. 175, https://doi.org/10.1007/s00410-020-01684-2.

Shamloo, H.I., and Till, C.B., 2019, Decadal transition from quiescence to supereruption: petrologic investigation of the Lava Creek Tuff, Yellowstone Caldera, WY: Contributions to Mineralogy and Petrology, v. 174, https://doi.org/10.1007/s00410-019-1570-x.

Simon, J.I., and Reid, M.R., 2005, The pace of rhyolite differentiation and storage in an "archetypical" silicic magma system, Long Valley, California: Earth and Planetary Science Letters, v. 235, p. 123–140, https://doi.org/10.1016/j.epsl.2005.03.013.