

What do trace element and argon systematics of melt inclusions tell us about magma generation, crystallization processes, and time scales in silicic magma chambers?

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The significance of the composition of melt inclusions in phenocrysts from silicic magma systems has been the source of much research over the past 10 years. Conclusions on the significance of the trace element, volatile component, and argon concentrations in rhyolitic melt inclusions have varied. Some studies suggest that composition of melt inclusions are representative of the magma chamber composition and can therefore be used to interpret magma chamber processes (e.g. Anderson et al., 2000; Wallace et al., 1999; Dunbar and Kyle, 1993; Dunbar and Hervig, 1992a and b; Hervig and Dunbar, 1992; Lu et al., 1992). Other authors consider that melt inclusions may provide some type of information about magma chamber processes, but may not be accurate representations of the trace element or volatile composition of the magma at the time of eruption. Wolff et al. (1999) suggested that the phenocrysts in rhyolitic magmas grow near the magma-wallrock interface and are disseminated into the melt only just prior to eruption. Van den Bogaard and Schirnick (1995) suggest that because of very long time spans between crystal growth and eruption, the melt inclusions record only the very early stages of magmatic evolution. In this abstract, we will consider a body of old and new data on melt inclusions from the Bandelier, Bishop and Taupo magmatic systems in order to provide insight into the question of what melt inclusion analyses can, and cannot tell us about rhyolitic magmas.

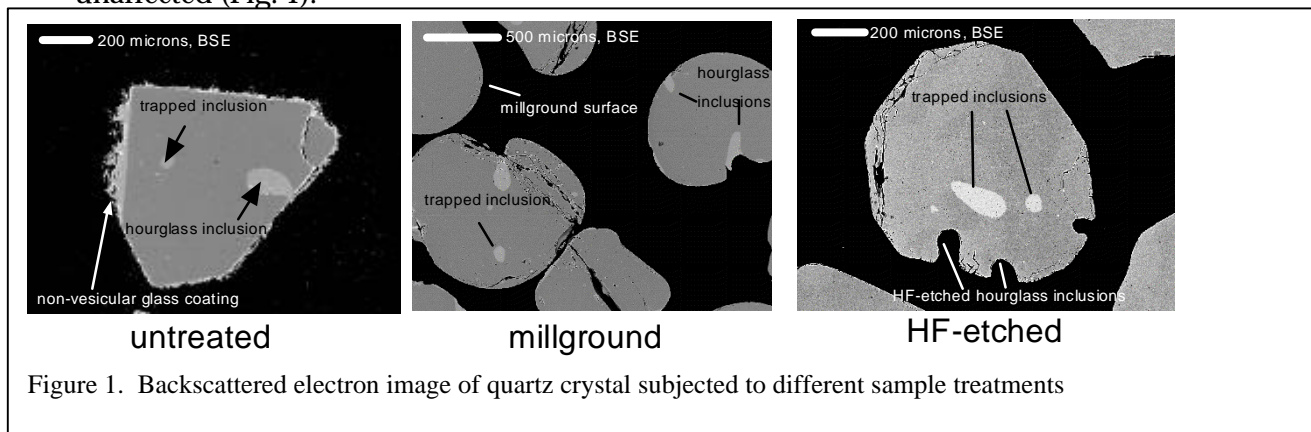
Trace element compositions of hundreds of melt inclusions in phenocrysts from the Taupo (186 A.D.), Bishop and Bandelier deposits have been analyzed (see references above). The simplest case to interpret is the Taupo eruption. The magma that produced all phases of the Taupo eruption was chemically homogeneous, and the trace element composition of all analyzed melt inclusions exactly matches that of pumice glass. The homogeneity of the magma, suggesting rapid and efficient convection, would argue for a short residence time prior to eruption, as would the frequency of eruptions from this magmatic center (Wilson et al., 1986). The close match between the melt inclusion and pumice glass compositions suggests that the inclusions are representative of melt compositions, and that the crystals grew from the melt with which they erupted.

The Bishop Tuff is thought to be derived from a chemically-zoned magma, with the coolest, most evolved magma erupted first, and the hottest, least evolved magma erupting last (Hildreth, 1979; Wilson and Hildreth, 1998). Melt inclusions analyzed from the Bishop Tuff tend to be most evolved in the plinian fall deposit, moderately evolved in the intermediate phases of the eruption (although there is overlap between the early and intermediate stages) and are geochemically distinct in the latest-erupted material. This compositional pattern suggests that melt inclusions were trapped in quartz growing in a chemically evolved, or evolving melt. Wallace et al. (1999) reached

this conclusion but found it difficult to reconcile the melt inclusion compositions with the apparently-long magma residence times suggested by van den Bogaard and Schirnick (1995). The observed chemical variability in the late-erupted portion of the Bishop Tuff is interpreted by Anderson et al. (2000) as a result of crystal settling, and by Hervig and Dunbar (1993) as magma mixing, but in either case is thought to be representative of a primary magmatic evolution process.

The Lower Bandelier Tuff is also thought to have been derived from a chemically-zoned magma chamber but the zonation underwent some disruption during eruption (Kuentz, 1986). Melt inclusions in the Lower Bandelier Tuff exhibit compositional variability very similar to that observed in the Bishop Tuff, with generally the most evolved inclusions found in the plinian fall, and the least evolved in the most primitive pumice lumps within the ignimbrite. However, based on Sr isotopic analyses, Wolff et al. (1999) suggest that inclusion-bearing crystals grew near the magma-wallrock contact and were mixed into the melt during eruption, and therefore are not representative of the magma as a whole. We would argue, based on the match between melt inclusion and pumice composition, that the Sr isotopic data may have been misinterpreted, possibly because the Sr isotopic analysis of multiple whole quartz crystals does not truly represent melt inclusion composition. We suggest that the melt inclusions in the Lower Bandelier Tuff are representative of the evolving magma and are valid indicators of trace element and volatile composition of the melt. The least-evolved portion of the Lower Bandelier Tuff, like the Bishop Tuff, shows a chemically-distinct component, and we suggest that the mechanism that caused this chemical effect, whether magma mixing or crystal settling, is similar in the two magmatic systems, and may also be present in other rhyolitic magmas.

One trace element that is of particular interest in magmas is Ar, because analysis of argon isotopes may allow the age of the sampled material to be determined. Based on analysis of the Ar-40 and Ar-39 concentrations in melt-inclusion-bearing quartz, van den Bogaard and Schirnick (1995) suggest long residence times of ~1.1 million years for the Bishop Tuff magma. These exciting results agreed with residence times estimated by some methods, but disagreed with others. We performed Ar-40/Ar-39 experiments on melt-inclusion-bearing quartz from the plinian fall deposits of the Bishop and Bandelier Tuffs. The analyses indicate high concentrations of excess Ar-40 in melt inclusions. Two rhyolite melt inclusion populations are present in quartz; exposed melt inclusions and trapped melt inclusions. Air-abrasion mill grinding and hydrofluoric acid treatments progressively remove exposed melt inclusions while leaving trapped melt inclusions unaffected (Fig. 1).



As glass is removed by the mill grinding and HF etching processes, the potassium concentration in the sample decreases, and the apparent age increases (Fig. 2).

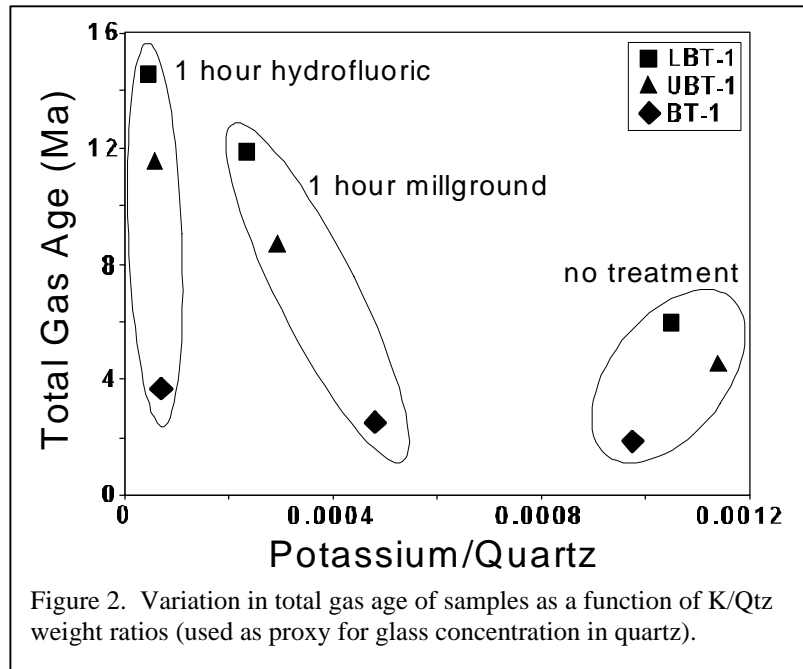


Figure 2. Variation in total gas age of samples as a function of K/Qtz weight ratios (used as proxy for glass concentration in quartz).

Laser step-heating of melt-inclusion-bearing quartz yields increasing apparent ages as a function of exposed melt inclusion removal, reflecting the higher non-atmospheric Ar-40 concentrations hosted in trapped melt inclusions relative to exposed inclusions and adhered glass. After removal of *exposed* melt inclusions, quartz from the Bishop, Upper Bandelier, and Lower Bandelier Tuffs yield total-gas ages of 3.70 ± 1.00 Ma, 11.54 ± 0.87 Ma, and 14.60 ± 1.50 Ma, respectively, for eruptions with accepted ages of 0.76, 1.24, and 1.63 Ma, respectively (van den Bogaard and Schirnick, 1995; Izett and Obradovich, 1994). These ages are far too old to be accurate records of magma residence time. We interpret these old apparent ages as compelling evidence for the presence of excess Ar-40 in melt-inclusion-bearing quartz, and suggest that although many trace elements in melt inclusions may be used to gain insight into processes of magmatic evolution, using Ar analyses of melt inclusions to determine eruption or residence ages is unlikely to succeed.

- Anderson, A.T., Davis, A.M., and Lu, F.Q., 2000, Evolution of Bishop Tuff rhyolitic magma based on melt and magnetite inclusions and zoned phenocrysts: *Journal of Petrology*, v. 41, p. 449-473.
- Dunbar, N.W., and Hervig, R.L., 1992, Petrogenesis and volatile stratigraphy of the Bishop Tuff; evidence from melt inclusion analysis: *Journal of Geophysical Research, B, Solid Earth and Planets*, v. 97, p. 15,129-15,150.
- Dunbar, N.W., and Hervig, R.L., 1992, Volatile and trace element composition of melt inclusions from the Lower Bandelier Tuff: Implications for eruptive style and magma chamber processes: *Journal of Geophysical Research*, v. 97, p. 15151-15170.
- Dunbar, N.W., and Kyle, P.R., 1993, Lack of volatile gradient in the Taupo plinian-ignimbrite transition: Evidence from melt inclusion analysis: *American Mineralogist*, v. 78, p. 612-618.
- Hervig, R.L., and Dunbar, N.W., 1992, Cause of chemical zoning in the Bishop (California) and Bandelier (New Mexico) magma chambers: *Earth and Planetary Science Letters*, v. 111, p. 97-108.
- Hildreth, W., 1979, The Bishop Tuff; evidence for the origin of compositional zonation in silicic magma chambers, in Chapin, C.E., and Elston, W.E., eds., *Ash-flow tuffs, 16 years after Smith (1960)*; The

- Geological Society of America, Rocky Mountain Section, annual meeting, Geological Society of America (GSA), p. 43-75.
- Izett, G.A., and Obradovich, J.D., 1994, $^{40}\text{Ar}/^{39}\text{Ar}$ age constraints for the Jaramillo normal subchron and the Matuyama-Bruhnes geomagnetic boundary: *Journal of Geophysical Research*, v. 99, p. 2925-2934.
- Lu, F., Anderson, A.T., and Davis, A.M., 1992, Melt inclusions and crystal-liquid separation in rhyolitic magma of the Bishop Tuff: *Contributions to Mineralogy and Petrology*, v. 110, p. 113-120.
- Kuentz, D.C., 1986, The Otowi Member of the Bandelier Tuff; a study of the petrology, petrography, and geochemistry of an explosive silicic eruption, Jemez Mountains, New Mexico [Master's thesis]: Arlington, TX, University of Texas Arlington.
- van den Bogaard, P., and Schirnick, C., 1995, $^{40}\text{Ar}/^{39}\text{Ar}$ laser probe ages of Bishop Tuff quartz phenocrysts substantiate long-lived silicic magma chamber at Long Valley, United States: *Geology*, v. 23, p. 759-762.
- Wallace, P.J., Anderson, A.T., Jr., and Davis, A.M., 1999, Gradients in H_2O , CO_2 , and exsolved gas in a large-volume silicic magma system; interpreting the record preserved in melt inclusions from the Bishop Tuff: *Journal of Geophysical Research, B, Solid Earth and Planets*, v. 104, p. 20,097-20,122.
- Wilson, C.J.N., and Hildreth, W.H., 1997, The Bishop Tuff; new insights from eruptive stratigraphy: *Journal of Geology*, v. 105, p. 407-439.
- Wilson, C.J.N., Houghton, B.F., and Lloyd, E.F., 1986, Volcanic history and evolution of the Maroa-Taupo area, Central North Island: *Royal Society of New Zealand Bulletin*, v. 23, p. 194-223.
- Wolff, J.A., Ramos, F.C., and Davidson, J.P., 1999, Sr isotope disequilibrium during differentiation of the Bandelier Tuff; constraints on the crystallization of a large rhyolitic magma chamber: *Geology*, v. 27, p. 495-498.