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Comment on "Evidence for long residence times of rhyolitic magma in the Long Valley magmatic system: the isotopic record in precaldera lavas of Glass Mountain" by A.N. Halliday, G.A. Mahood, P. Holden, J.M. Metz, T.J. Dempster and J.P. Davidson

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Halliday et al. [1] have presented superb isotopic data on high-silica rhyolites from Glass Mountain, Long Valley. The data demonstrate unequivocally that the rhyolites can be divided into groups in which chemical fractionation of Rb and Sr occurred as well-defined events on times scales of a few tens of thousands of years or less. Geochronological studies show that the same magmas were subsequently erupted over periods of up to 700,000 years following the discrete fractionation events. Halliday et al. interpret these data to indicate the presence of long-lived (300,000–700,000 years), high-level, large-volume magma chambers. They suggest that their data are inconsistent with the ideas presented by Huppert and Sparks [2] in which silicic magmas can be generated rapidly by melting due to intrusion of basalt into the crust. In this discussion we argue that the evidence for the long residence time of magmas is not conclusive. We suggest that the data are more consistent with a model in which remelting of a granite source region takes place episodically and the residence times of magma bodies are short.

There are two principal problems with the model of Halliday et al. First, the time and space relationships of the rhyolites are difficult to reconcile with the notion of long-lived physically separate, isotopically distinct magma bodies. Lavas representative of the three isochron-defined magma batches were erupted from vents up to 12 km apart so the presumed magma bodies would have to be of these dimensions across. Yet the two distinct older lava types (with Rb–Sr isochrons of 2.09 and 1.90 Ma) have erupted in closely adjacent areas with no apparent mixing. For example lava ON (1.77 Ma eruption age, 2.09 Rb–Sr isochron magma batch) erupted adjacent to the earlier lava OP (1.8 Ma eruption, 1.90 Rb–Sr isochron age). Were the two magma batches to be liquids simultaneously, as Halliday et al. suggest, the field relationship would require extraordinarily special plumbing arrangements to prevent the two magma batches ever meeting and mixing after 1.90 Ma.

Second, there are problems with rationalising the existence of separate chemically-zoned magma bodies over a period of 300,000–700,000 years which stayed exactly the same, without significant cooling or further fractional crystallization. Halliday et al. suggest that the system was maintained by influx of basaltic magma. However, the rate of heat input must then have precisely balanced the heat loss from the top of the rhyolitic magma bodies. This remarkably delicate balance must have been repeated on at least three separate occasions (the 2.09, 1.90 and 1.14 Ma magma batches). The time-scales are also sufficiently long that the magma bodies would have effectively reached thermal equilibrium with the crustal geothermal gradient, so that their emplacement was at those depths where the surrounding crustal tem-

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peratures were comparable to the magma temperatures. Also, the temperature gradient across the chemically zoned magma chamber would have to equal the local geothermal gradient to avoid heat loss or gain over the period. If the longevity concept is correct then these are remarkable coincidences and require explanation.

An alternative interpretation to the Halliday et al. model of long-lived magma bodies is that the three magma bodies were formed rapidly by major thermal pulses and then solidified shortly thereafter. The temperatures within these plutonic rocks would not need to be constrained. The solid rocks would evolve isotopically without any problems related to preventing heat loss from a magma body or maintaining constant temperatures. We suggest that the eruptions of magma over the following few hundred thousand years coincided with episodic influxes of mafic magmas into these plutonic source rocks causing them to melt and erupt at the surface as rhyolitic lavas and pyroclastics. Huppert and Sparks [2] present calculations which predict that the magmas formed could be close to their liquidus or even superheated. Rhyolitic magmas are sufficiently viscous that high temperatures can be achieved during remelting by basaltic underplating. In this model there is no long-lived magma chamber, but episodic production of magma batches from discrete source regions of evolved and recently formed granites.

The sanidine separates reported by Halliday et al. [1] are out of isotopic equilibrium with co-existing glass and sit slightly above the isochrons. This result would not be expected if the crystals had grown late in the history of a long-lived system, immediately prior to eruption. On the other hand if the crystals had grown relatively early, then it is required that the crystals did not equilibrate isotopically with their host melt over extraordinarily long times. The remelting model resolves this dilemma. Huppert and Sparks showed that the phenocrysts in magmas formed during remelting would have a component of restite and a component of newly grown crystals. These components would not necessarily be distinguishable optically because new crystallization would take place on a restite nucleus. Only crystals that develop good zoning like zircon or plagioclase would preserve restite cores. Huppert and Sparks also calculated rapid melting time-scales of tens to hundreds of years over which period it would seem plausible to preserve some isotopic disequilibrium in the phenocrysts.

In the specific case of Glass Mountain, the remelting model only requires the mafic influxes to have intruded into a specific kind of highly fractionated host rock to generate the observed rhyolites. The geographic distribution of the 2.09 and 1.90 Ma isochron magma batches as represented by the Older lavas would then reflect the surface projection of the two older granite intrusions. The 1.14 Ma intrusion could have been emplaced at a different crustal level, and the density trap afforded by the granite served to focus mafic intrusions within itself to cause further melting. We submit that the remelting model is physically more plausible and involves fewer coincidences and difficulties than the long-lived magma chamber model.

We dispute that a rigorous case has yet been made for long-lived magma chambers at Long Valley. The volume of magma erupted at Glass Mountain during the Older lava period from 2.1 to 1.2 Myr is not substantial (~ 10 km^3) and does not necessarily imply the continued existence of a large chamber. The Bishop Tuff was manifestly erupted from a large body (~ 1000 km^3) of chemically zoned magma, but for reasons outlined in this discussion, the isotopic evidence does not indicate that this magma chamber existed for the 400,000 years prior to the Bishop Tuff eruption. The data merely suggest that the fractionated source rocks, from which the Bishop Tuff magma was generated, could have been formed at 1.1 Myr. The well-defined isochrons of Halliday et al. [1] with errors of only a few tens of thousands of years indicate that zoned magma bodies can be generated and fractionated on relatively short time-scales. Alternatively the isochrons are dating periods of rapid influx of basalt into the crust where large volumes of rhyolite are generated and fractionated. Over much of the history of Long Valley the basaltic influx was lower, and no substantial chamber existed. Instead we envisage a plumbing system with hot but consolidated silicic intrusions which were remobilised when basaltic magma was intruded.

Finally, we congratulate Halliday et al. [1] on generating such a splendid and thought-provoking data set.

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References

1 A.N. Halliday, G.A. Mahood, P. Holden, J.M. Metz, T.J. Dempster and J.P. Davidson, Evidence for long residence times of rhyolitic magma in the Long Valley magmatic system: the isotopic record in precaldera lavas of Glass Mountain, Earth Planet. Sci. Lett. 94, 274–290, 1989.

2 H.E. Huppert and R.S.J. Sparks, The generation of granitic magmas by intrusion of basalt into continental crust, J. Petrol. 29, 599–624, 1988.