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Short Crystal Residence Times and Complex Magmatic Evolution of the 3000 km^3 Youngest Toba Tuff

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About 74,000 years ago, the 100 x 30 km Toba caldera was formed when the roof of a magma chamber collapsed, disgorging 3,000 km^3 of silicic magma (Rose and Chesner, 1987). This eruption covered an area of at least 20,000 km^2 with an ignimbrite (Youngest Toba Tuff) more than 100 m thick, and deposited co-ignimbrite ash as far afield as India. It loaded the stratosphere with 2 to 4 billion tonnes of sulphuric acid aerosol that may have caused a rapid global cooling of between 3 and 5 C (Rampino and Self, 1992).

We present new major element, trace element and radiogenic isotope data for whole rocks (single pumices) and minerals from the Youngest Toba Tuff. Our aims are firstly to trace the pre-eruptive origin and evolution of the Toba magma body, and secondly to identify the processes which triggered this devastating eruption and the timescales over which the system evolved.

The erupted magmas are compositionally and isotopically heterogeneous on single crystal to whole rock scales, testifying to an origin on timescales that were too short to homogenise compositional differences. The YTT has a high crystallinity (15-40%) and the main mineral phases are plagioclase, biotite, sanidine, quartz and hornblende, with accessory phases such as zircon, magnetite, ilmenite and sphene. On the basis of whole rock geochemistry, there are two separate types of pumice, an A group (SiO_2 67-74%; Ba/Rb >3, $^{87}Sr/^{86}Sr = 0.7134 \pm 5$) and a B group ($SiO_2$ 73-76; Ba/Rb <2; $^{87}Sr/^{86}Sr = 0.7139$).

YTT plagioclases and biotites display a marked compositional bimodality. The type 1 crystals are seen in A group samples of <72% SiO_2 and the type 2 are present in the B group and the A group pumice >71% SiO_2. The An% in plagioclases range from 23-79% in the type 1 and 23 to 55% in the type 2; the most calcic compositions are not in equilibrium with their host rocks. The plagioclases show complex zonations including reverse, oscillatory and normal patterns in the same rock. Individual rocks may show a restricted range of plagioclase compositions indicating in-situ growth, or a bimodal distribution indicating simple mixing, or a large range implying complex processes of mixing and inefficient re-equilibration.

Trace element concentration profiles in selected plagioclase, sanidine and biotite crystals were analysed by ion probe. The results were used to evaluate the sequence of liquid compositions from which these crystals grew and to place limits on the timescales involved by applying a model for diffusive degradation of trace element zoning. Positive correlation between trace elements such as Ba and Sr confirms the argument that the highest trace elements are seen in the highest An% bearing parts of the crystals. However the larger scale traverses sometimes show reversals in trace element contents that are at odds to the overall correlation.

Using the methods of Blundy and Wood (1991) and Bindeman et al (1998) to calculate D values as a function of An content and temperature, liquid compositions were modelled from plagioclase compositions. The temperatures range from 700 (low An%) to 1100 ºC (high An%). The reversal in compositions in the different regions of a crystal may reflect crystal recycling between magma batches undergoing different degrees of fractionation and assimilation. Conventional models of evolution along a single liquid line of descent are inadequate to model this major magma body and that coupled with melting, crystal fractionation and mixing processes are implicated.

The residence times of crystals in crustal magma chambers may be constrained by amount of diffusive relaxation of trace element profiles in plagioclase crystals (Zellmer et al. 1999). This method was applied to the Sr zonations in the plagioclase crystals of the YTT and yielded maximum residence times from 1000 to 3000 years. This approximately 10^3 year residence time is much shorter than the time interval of 0.43 Ma between the YTT and the next oldest eruption the Middle Toba Tuff. Hence this challenges the conventional assumptions of a protracted evolution and an orderly evolution along a liquid line of descent.

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