# The space and time complexity of chaotic mixing of silicate melts: implications for igneous petrology

PERUGINI D.[1], DE CAMPOS C.P.[2], ERTEL-INGRISCH W.[2] AND DINGWELL D.B.[2]

[1]Department of Earth Sciences, University of Perugia, Italy (diegop@unipg.it)
[2]Department of Earth and Environmental Sciences, Ludwig-Maximilian-University, Germany

We present new experimental results on the study of the space and time modulation of compositional fields during chaotic mixing between mafic and felsic silicate melts. The experimental strategy was planned using numerical simulations performed using the experimental geometry. These mixing experiments were performed using a recently developed experimental apparatus, which is capable of mixing high-viscosity silicate melts at high temperatures and under precisely controlled conditions of fluid-dynamics and strain. The compositional variability produced by the mixing process was investigated both along linear analytical transects and on high-resolution 2D X-ray maps, covering the mixing patterns.

Our results indicate that chaotic flow fields represent very powerful dynamics to blend silicate melts, even under laminar fluid dynamic conditions (Reynolds number ca. $10^{-7}$) and for dissimilar melts with high viscosity ratios (on the order of $10^3$). The repetition of stretching and folding processes between the two melts induced a strong increase of contact interfaces thus favoring efficient chemical exchanges. As a result the initial mafic composition is no longer detectable in the mixing system after ca. 2 h (i.e. the duration of the experiment). A further important result is the observation of highly non-linear patterns in inter-elemental plots produced by the onset of diffusive fractionation processes. This is contrary to common thinking that magma mixing should always produce linear trends between pairs of chemical elements.

A new measure, the "concentration variance", is proposed to quantify chemical element mobility during the mixing process. This measure is statistically robust and can be quantitatively used to measure chemical element mobility independently of the geometry in which the compositional variation (i.e. transects, areas, etc.) is embedded or the local strain history of the mingling.

Our results highlight concentration variance as a robust probe of the as yet poorly-understood processes involved in the common petrological process of magma mixing.

# Concentration variance decay during magma mixing: a volcanic chronometer to measure magma ascent velocity during explosive eruptions

PERUGINI D.[1], DE CAMPOS C.P.[2] AND DINGWELL D.B.[2]

[1]Department of Earth Sciences, University of Perugia, Italy (diegop@unipg.it)
[2]Department of Earth and Environmental Sciences, Ludwig-Maximilian-University, Germany

The ability of chemical elements to diffuse in silicate melts controls the rates of crystal growth and dissolution kinetics, the rate of homogenization of compositional gradients generated by fractional crystallization and assimilation of country rocks as well as one of the most intriguing processes of all, magma mixing. In the context of mixing the time dependence of mass transfer processes constitutes a powerful tool to define geochemical clocks to estimate timescales of magma dynamics and eruption.

Here we aim to understand the timescale of chemical element mobility during mixing to define a chronometer to dechiper the ascent velocity of magmas during explosive volcanic eruptions. The mixing process was induced experimentally using a high-temperature centrifuge apparatus under controlled thermal and rheological conditions.

Using this novel laboratory-based time-series experiments, we show that the Concentration Variance Decay (CVD, an inevitable consequence of magma mixing) is exponential with time and represents a powerful geochronometer to measure the time from mixing to eruption/quenching.

The mingling-to-eruption time of some explosive volcanic eruptions from Campi Flegrei (Italy) yield durations on the order of tens of minutes. These imply very rapid ascent velocities of 5-8 meters per second.

Application of the CVD geochronometer to the eruptive products may provide unprecedented information about trasport of magmas in active volcanoes and could be decisive for the preparation of volcanic hazard mitigation during volcanic unrest.

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