Magma decompression rate calculations with EMBER: A user-friendly software to model diffusion of H_2O, CO_2 and S in melt embayments

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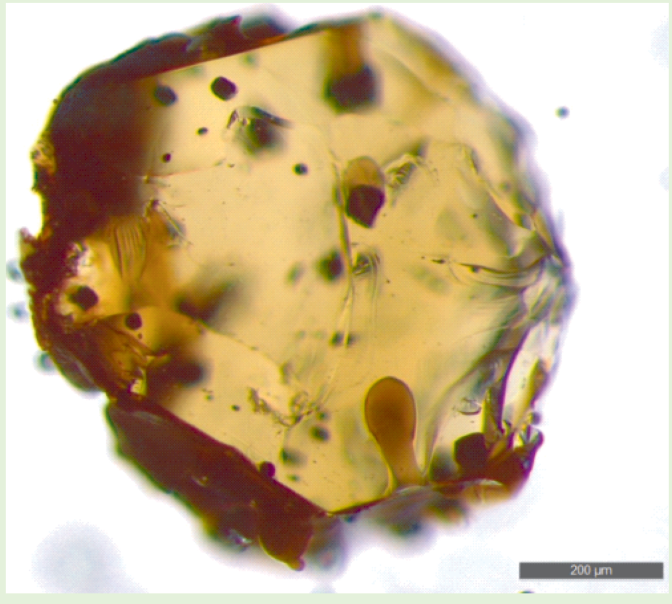
1. Introduction

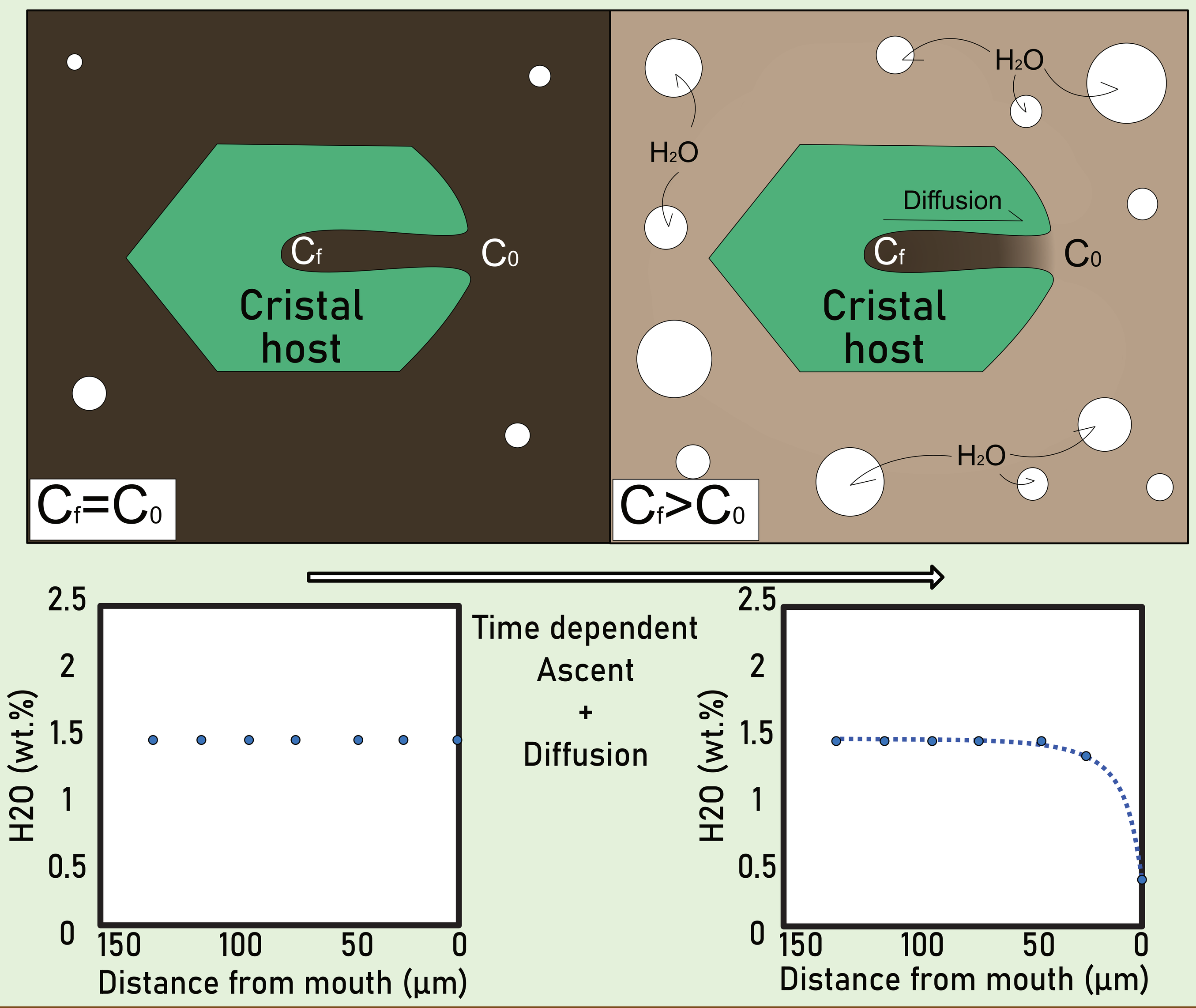
The ascent rate of magmas during volcanic eruptions is a challenging parameter to decipher yet a key in controlling eruption dynamics. The embayment method holds the potential to be applied for a wide range of composition and relies on fitting volatile elements diffusion profiles along a concentration gradient in crystal-hosted open melt pockets [e.g. Liu et al, 2007, Lloyd et al, 2014]. This method has been applied on quartz and feldspaths for dacitic to rhyolitic eruptions and on olivines for more basaltic ones. We introduce **EMBER (EMBayment-Estimated Rates)**, (1) a free tool to estimate the decompression rate of magma, (2) models the diffusion of up to 3 volatile element at once (H_2O, CO_2 and S), (3) can be applied to a range of SiO_2 from basaltic to rhyolitic, (4) assesses the initial concentration of volatile in magmas



Take home messages

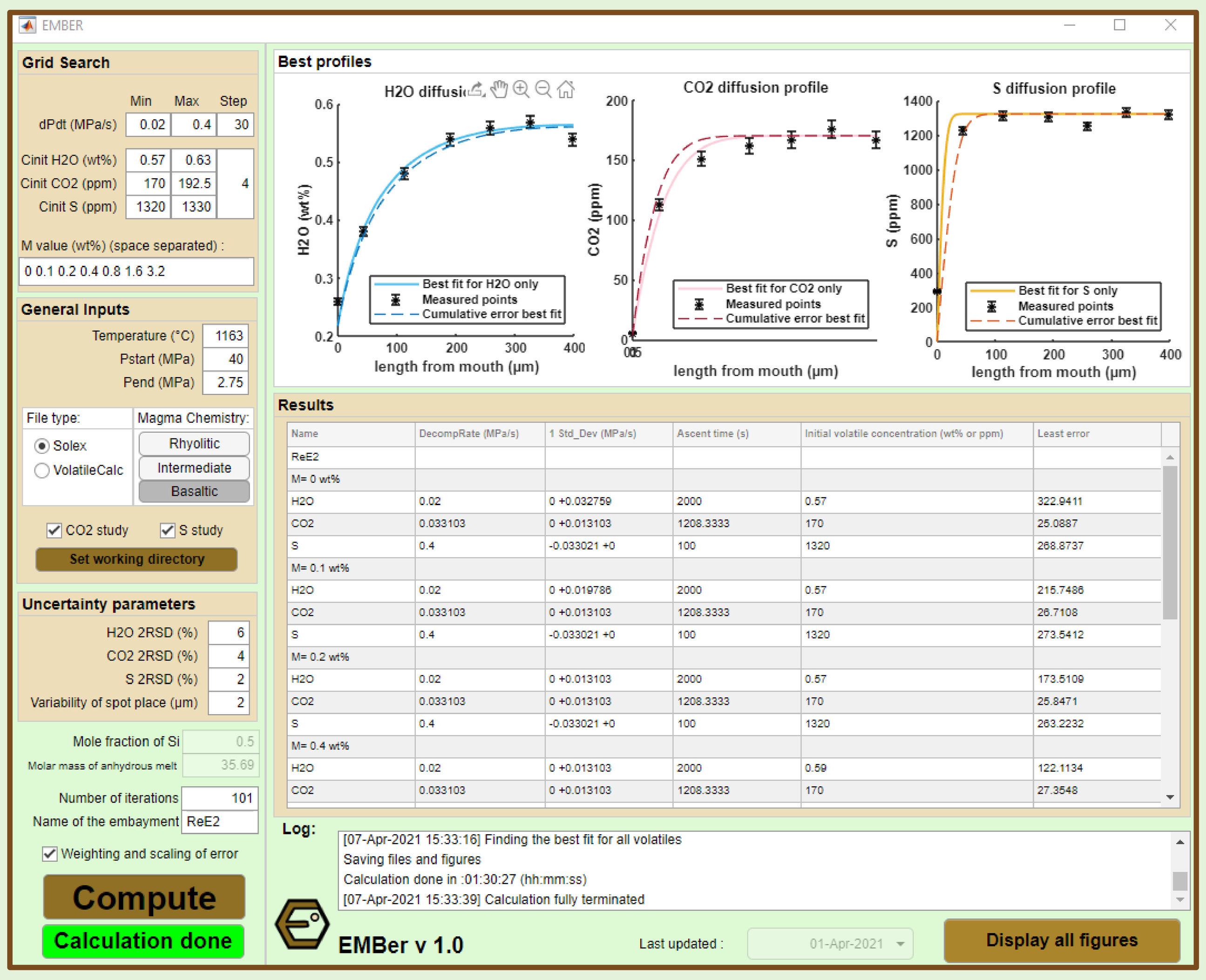
- **EMBER is an user-friendly GUI program** that calculates decompression rates from H_2O, CO_2 and S concentration profiles along embayments of basaltic to rhyolitic compositions.
- EMBER was validated by reproducing previous published literature data.
- For mafic eruptions, we found a notable correlation between maximum recalculated decompression rates and eruption magnitude or plume height (Pearson coefficient of 0.93 with a p-value of 0.01 and R^2=0.86).

2. Embayment method



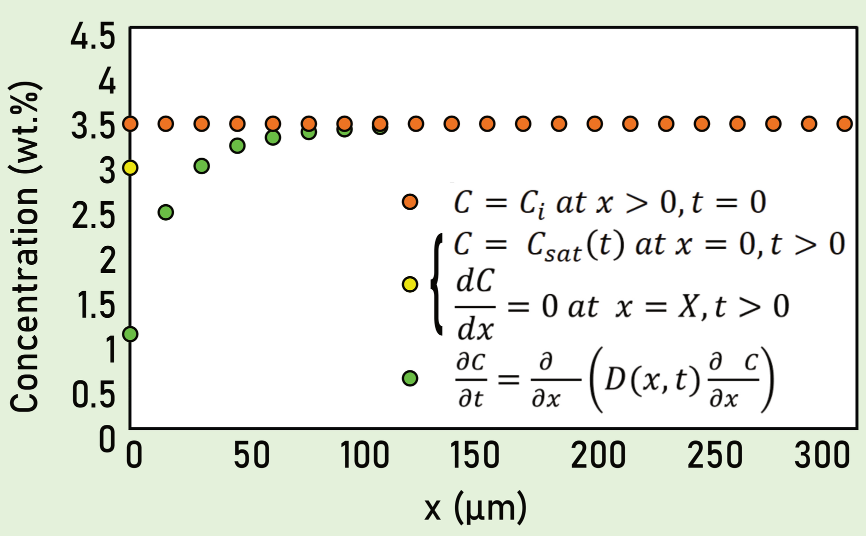
During the ascent, volatile concentration decreases in the melt but not in the embayment. The difference in chemical potential and the resulting concentration gradient is re-equilibrated along the embayment through volatile diffusion, gradually forming a time-dependent diffusion profile. This method requires a numerical model to reproduce the measured diffusion profile and find the eruption-related parameters, like the diffusion duration and therefore the decompression rate, through inversion calculation.

3. EMBER (EMBayment-Estimated Rates)



EMBER's GUI is standalone and generated with the **free Matlab Runtime environment**. It is split into two parts inputs (left) and results (right). Several 2D and 3D figures are also generated showing the evolution of the best solution along the 3 mains parameters of the grid search for each studied volatile (H2O, CO2 and S).

Profile generation



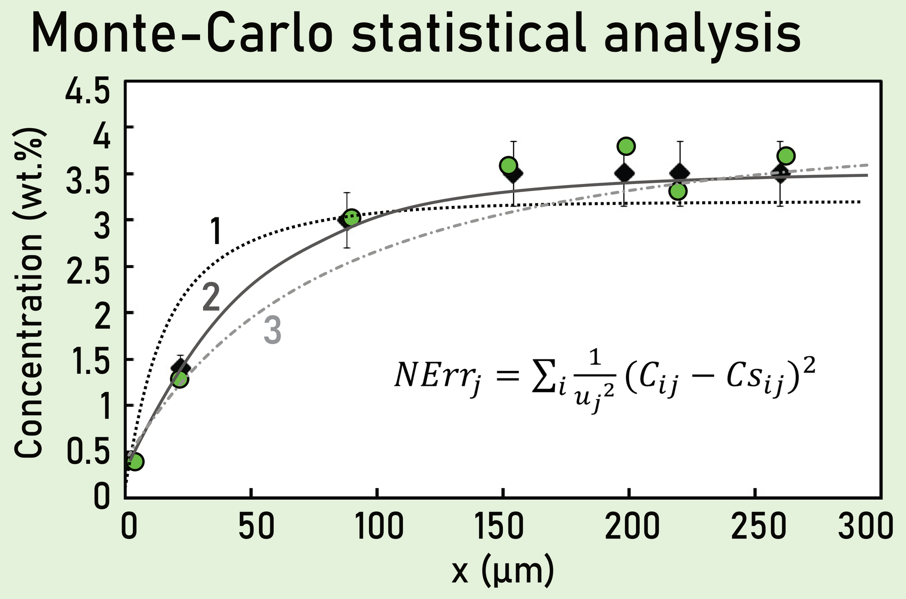
$$C = C_i \text{ at } x > 0, t = 0$$
$$C = C_{sat}(t) \text{ at } x = 0, t > 0$$
$$\frac{dC}{dx} = 0 \text{ at } x = X, t > 0$$
$$\frac{\partial C}{\partial t} = \frac{\partial}{\partial x}\left(D(x,t)\frac{\partial C}{\partial x}\right)$$

Calculation in two steps:

-Generation of diffusion profiles according to the grid search parameters following the 4 equations of initial and boundary conditions, and Fick's second law.

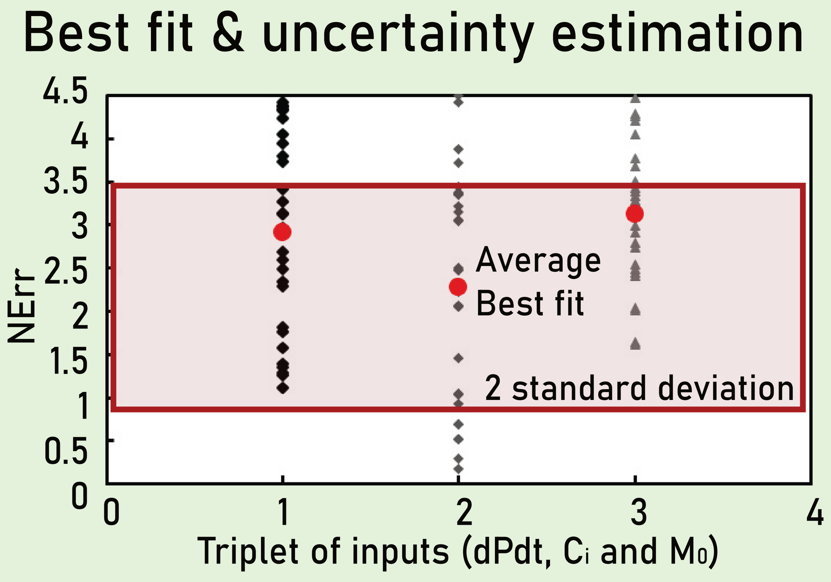
-Determination of the best fitting profile with a Monte-Carlo statistical analysis. The best fit, with the lowest error, is the profile generated with the resulting decompression rate. and initial concentrations.

Monte-Carlo statistical analysis



$$NErr_j = \sum_i \frac{1}{u_j^2}(C_{ij} - Cs_{ij})^2$$

Best fit & uncertainty estimation

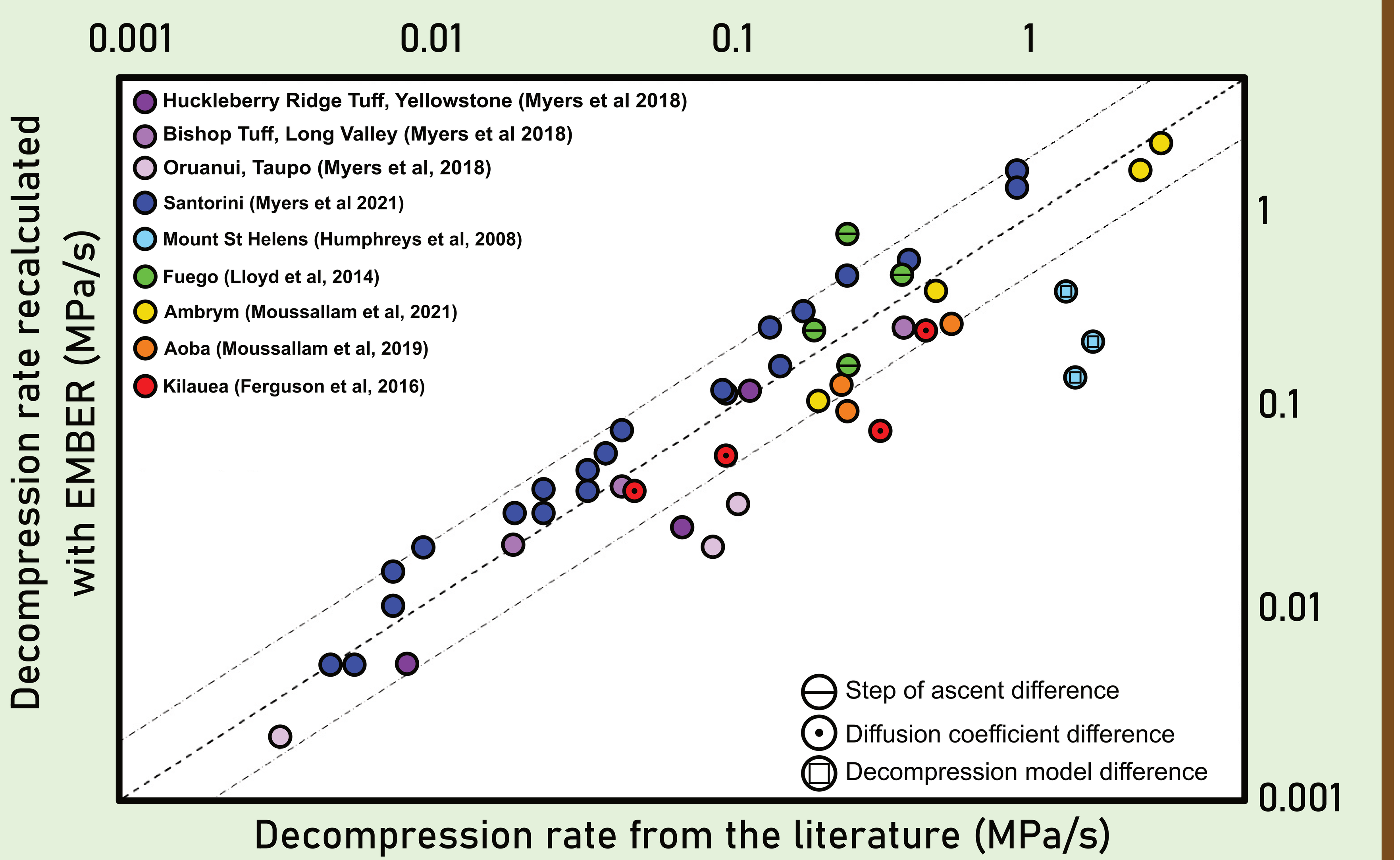


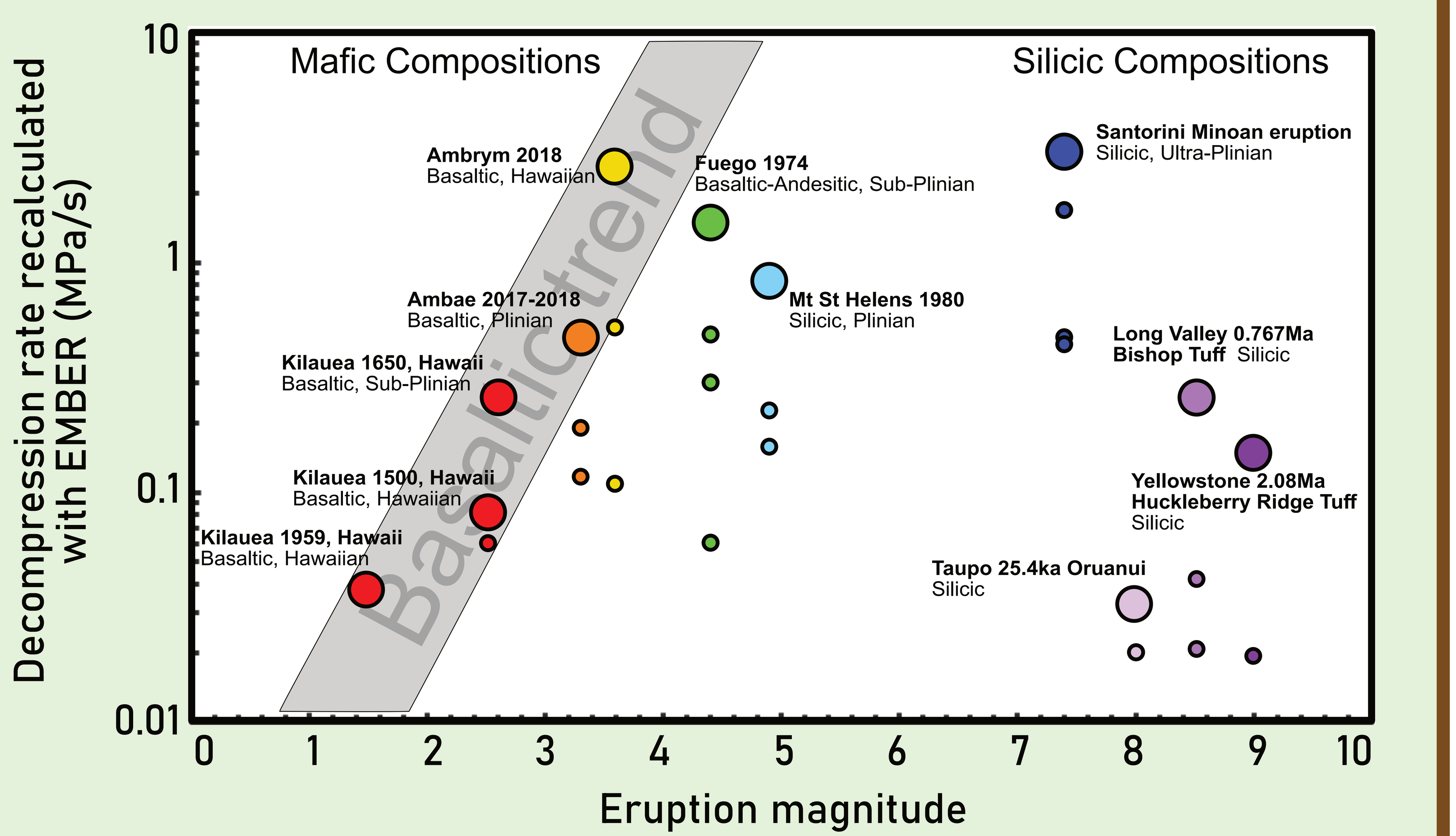
4. Results and discussions

We recalculated decompression rates from previous studies twice: first, to validate and test how well EMBER reproduced existing results using the parameters from the original studies, and secondly, to homogenize determined decompression rates applying the same protocol to the existing raw data from previous studies, in order to improve inter-study comparison.

In the first case, **recalculated decompression rates are in the same order of magnitude as original calculations** but notable differences do occur such as for the 1980 Mt St Helens eruption which recalculated decompression rate are at 0.15-0.41 MPa/s, half of the previously reported values [Humphreys et al., 2008].

In the second case, recalculated dataset shows no significant correlation between **magma decompression rate and eruption magnitude** when considering the entire dataset and **shows a weak correlation** when considering the subset of decompression rates of **basaltic magma** (Pearson coefficient of 0.24 with a p-value of 0.35 and R^2=0.47.) The correlation is **significant** when considering only the **maximum decompression rates of each basaltic eruption** (Pearson coefficient of 0.93 with a p-value of 0.01 and R^2=0.86). Additionally, there is no significant correlation between decompression rate and plume height when considering the entire dataset. However, once again, a statistically significant trend appears when considering only the maximum decompression rate of the basaltic eruptions (with a Person coefficient of 0.84, a p-value of 0.007 and R^2=0.88).





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Publication

Software