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Application of single crystal Sr isotope diffusion modeling to determine timescales of flood basalt eruptions

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Age dating of large scale volcanic eruptions like the Deccan has shown that a volumetrically large proportion of the lava flows (80-90%) was erupted in geologically short pulses lasting $\sim$1 Ma. However, the duration of these events cannot be constrained better than the $\pm$1 Ma error of the commonly used radiometric methods. We present a study on the Deccan Basalts where we use diffusion modeling to determine residence times of crystals and attempt to relate it to magma eruption rates. In the Deccan, the bulk of the lavas erupted at $\sim$65.5 Ma giving rise to the Western Ghats region in west-central India. We concentrate on the two oldest formations from the Western Ghats, each of which include a unique type of flow called the Giant Plagioclase Basalts (GPB), with 2-5 cm long plagioclase phenocrysts. We analyzed these phenocrysts using LA-ICPMS and EPMA and measured in-situ, within-crystal variations in Sr isotope ratios, trace element concentrations and major element concentrations. We found that crystals from the two GPB flows show completely different zoning schematics. Zoning in major and trace elements is practically nonexistent, while zoning in Sr isotope ratios is strong, the variation being 0.0016 within a distance of few hundreds of microns. This large variation in isotopes points to growth from separate magmas that had very similar compositions but widely different degrees of contamination.

We selected crystals which showed simple core-rim zoning in Sr isotopes and modeled the variation as diffusion profiles. These crystals have a core grown in a magma

of lower Sr ratio and a rim grown in equilibrium with a higher Sr ratio magma that erupted carrying these crystals within it. We use a step-like initial profile from the low $^{87}Sr/^{86}Sr$ core to the higher $^{87}Sr/^{86}Sr$ rim and apply a fixed boundary condition equal to the higher $^{87}Sr/^{86}Sr$ value to the edge of the crystal domain. Using finite difference modeling we obtain a maximum timescale of 200 years for diffusive equilibration. Liquid line of descent modeling shows that plagioclase begins to crystallize a few degrees below the liquidus, and continues to crystallize to the solidus i.e. plagioclase growth is continuous. As soon as the rim of the crystal grows over the core, diffusion will be initiated, due to the strong core-rim variation. Growth and diffusion will both stop more or less simultaneously, since Sr diffusion has a high closure temperature $\sim$800 degrees C, and a very small albitic rim shows that growth at lower temperatures was minimal. Diffusion and rim growth will thus be simultaneous, and the diffusive timescale can be taken to be the timescale of rim growth. Hence we obtain a rim growth rate of 2.03E-10 cm/s which compares well with other growth estimations. If we apply this growth rate to all crystals in the lava flow, we obtain a maximum residence time of 780 years which is the incubation + eruption time of the host lava. This timescale can be extended to other flows if it can be shown that the crystal was in equilibrium with other flows from the package; this is observed in one of the formations. Further work on a complete section of the Deccan would enable us to calculate a definitive eruptive timescale of the Deccan. If we extrapolate the timescales of our lava flows to the entire Deccan, we obtain a timescale of 25,000 – 35,000 years, which shows that this technique has the capability of measuring eruptive activities at a resolution beyond what is possible using typical radiometric methods.