Average magma ascent rate and xenolith-entrained depth constrained by thermal effect on crustal xenoliths

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Xenoliths are one of the important sources for clues on crustal structure and magma ascent rate. However, determination of xenolith-entrained depth is not straightforward especially for thermally affected xenoliths, in which mineral assemblage and compositions have been modified. In addition, commonly used Stokes' settling law only indicates the minimum magma ascent rate required to transport xenoliths to the surface. To overcome some of the limitations, we considered the timescale of heat transfer and disequilibrium phenomena of xenolith melting. We performed a non-steady-state 1-D thermal conduction model in spherical coordinates, varying initial temperature conditions and xenolith size. The model involves latent heat of fusion and temperature-dependence of thermal conductivity. Boundary conditions specified temperature, where xenolith surface has constant temperature as the host magma. This implicitly assumes that the xenoliths are volumetrically insignificant. Melt productivity in xenolith, which is also essential in the calculation, is based on phase equilibria but the effect of disequilibrium melting is also considered. Therefore, melt proportions at a given position increase by increasing both the degree of superheating and the heating time until melt proportions reach the values expected from phase equilibria. As an example, the above model was applied for Cretaceous granitic xenoliths entrained in a Miocene intermediate dike in NE Shikoku, SW Japan. Unknown initial xenolith temperature (T_0) was estimated using a xenolith entrained-depth and a geotherm gradient for shallow crust (30˚C/km). For xenoliths with 10–60 cm in diameter and T_0 of 40–460˚C enclosed by a host magma with 900˚C, it took ˜0.3–12 hours to reach solidus temperature at the xenolith center. If disequilibrium melting is assumed, longer time (order of days) is required for 5% melting at the xenolith center. Based on the resultant timescale, we can constrain the combination of average magma ascent rate and entrained-depth that explains the observed xenolith texture (i.e., the presence or absence of glass at the center of a xenolith). The approach proposed here would be applicable for other crustal xenoliths as long as the xenoliths were entrained in ascending magmas.

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