Rates of crystal nucleation and growth from inversion of natural crystal size distributions

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Magmatic textures provide sensitive record of physical processes and variables during magma solidification. Quantitative characterization of texture is thus a useful tool for interpreting the thermal regime and rates of crystal nucleation and growth. Here we show that different pairs of nucleation and growth rate functions can result in textures having identical crystal size distributions (CSD). In order to eliminate such ambiguity of CSDs, we use time variation in crystallinity as an additional constraint leading to unique nucleation and growth rates. While the nucleation rate strongly depends on the CSD slope, curvature and fluctuations, the character of growth rate curve is more related to changes in crystallinity. When crystallinity increases quasi-linearly with time, the growth rate diverges to very high values at the beginning and the end of crystallization, due to small area of solid-liquid interface. That is, the growth rate is slowest at moderate crystallinities, when the crystal surface area is largest. This transient behavior also facilitates approach to equilibrium. When we employ relevant thermal cooling model and bracket the total crystallization by liquidus and solidus temperatures, we can estimate the total crystallization time, and scale all rate functions into real units. Estimated rates of crystal growth are inversely proportional to magma chamber size, and increase non-linearly from its interior to the margin. Application to solidification time and CSDs of the Hawaiian lava lakes results in growth rates of about 10^{-11} cm s^{-1}, which is in good agreement with natural observations. The growth rates can be converted to crystallization time for any grain size of interest. In log-linear CSDs, the growth time of the most abundant grain size varies from $\sim 1/10$ of the characteristic cooling time for crystals in the pluton interior to $\sim 1/400$ for those near the contacts. Relative growth times thus depend on neither a CSD slope nor a magma body size. The changes in crystal size with time allow us to predict the distance of movement due to action of gravitational forces. The crystal travel distance increases quadratically with the magma chamber size, rendering the crystal settling to be most efficient in large reservoirs. For kilometer-sized bodies we predict that a crystal moves across half of a magma chamber even in viscous magmas, up to 10^9 Pa. s.

Stability and breakdown of Ca^{13}CO$_3$ melt combined with formation of ^{13}C -diamond in static experiments up to 80 GPa and 4000 K

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PT conditions of Ca^{13}CO$_3$ melting, stability of the melts, and their decomposition by the reaction Ca^{13}CO$_3$ = CaO + ^{13}CO$_2$ (fluid) are investigated at static pressures of 8.5 – 80.0 GPa and temperatures of 1900 – 4000 K with the use of diamond anvil cell and laser heating. The occurrence of ^{13}CO$_2$ is accompanied by formation of ^{13}C-diamond (above 11 GPa) and ^{13}C-graphite (below 11 GPa) that is indicative for the ^{13}CO$_2$ breakdown to ^{13}C and O$_2$. Another 'solution-melt' mechanism of isotope-pure ^{13}C-diamond synthesis was realized in melts of the carbonate Ca^{13}CO$_3$ - ^{13}C-graphite (metastable phase) system in the multianvil press at pressures 8.5 and 20 GPa and temperatures up to 2500 K. It was first found in static high pressure experiment that melting of Ca carbonate is congruent over a wide 11.0 – 80.0 GPa pressure interval at temperatures up to 3400 K. It is also important that the phase region for the Ca carbonate melts is sufficiently wide extending from 2300 to 3500 - 3800 K at the 20.0 – 80.0 pressure range. Of particular interest is the first experimental evidence for diamond formation in the two-phase region CaO + CO$_2$ (fluid). The use of isotope-distinguished carbonate Ca^{13}CO$_3$ in the diamond anvil cell experiments gives an unambiguous evidence that ^{13}C-diamond has been formed from Ca^{13}CO$_3$ melt by a two-stage decomposition reaction: (1) Ca^{13}CO$_3$ (melt) = CaO + ^{13}CO$_2$ (fluid) and (2) ^{13}CO$_2$ (fluid) = ^{13}C (diamond) + O$_2$.

The results are applied to the construction of PT phase diagram for the CaCO$_3$ join (of the CaO – C – O$_2$ system) up to 80 GPa and 4000 K. The melting and decomposition relations of the CaCO$_3$ join as well as accompanying processes of diamond formation are applied and discussed in the context of the problem of natural 'super deep' diamonds origin in carbonate-rich growth media of the transition zone and lower mantle of the Earth.