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Construction rates of ultramafic-mafic intrusions in the Earth's crust from U-Pb zircon geochronology

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Knowledge of the relative timing, duration, and rates of ultramafic-mafic magmatism in the crust is critical for understanding magma generation and transport mechanisms, crystallization processes in magma reservoirs, mineralization potential, and eruption timescales. Plutons in silicic-intermediate magmatic systems have complex emplacement histories over timescales of 1000s to millions of years with emplacement rates of the order of 10^{-2} to 10^{-4} km^3 per year. Pluton building rates for ultramafic-mafic magmatic systems have been significantly less studied and constrained. Recognition that zircon crystallizes in ultramafic-cumulates from highly fractionated interstitial melts at near-solidus temperatures has opened up the possibility of assessing their crystallization ages and cooling histories. Integrated U-Pb zircon geochronological frameworks, coupled with temperature-composition systematics, are revealing similar magma volume-duration relationships from across a range of tectonic settings and magma compositions for ultramafic-mafic compared to intermediate-silicic intrusions. Closed-system mafic intrusions (Skaergaard, Kiglapait) are predicted to fully crystallize over relatively short timescales (10s to 100s of thousands of years) with cooling rates determined primarily by magma volume and temperature, depth of emplacement, and country rock thermal properties, in addition to the extent of heat advected by active hydrothermal systems. Evidence for extended durations of magmatism (millions of years) and non-sequential emplacement in some Precambrian ultramafic-mafic intrusions (Stillwater, Bushveld) indicates a commonality of processes during the emplacement and crystallization of very large, open-system intrusions as stacks of amalgamated sills. For the Bushveld Complex, the estimated construction rate ($>10^{-1}$ km^3 per year) is distinct from all other intrusions and equivalent to those determined for Phanerozoic large igneous provinces. Collectively, these results are contributing to a paradigm shift in how the emplacement and crystallization of many ultramafic-mafic intrusions are viewed. This change is from a conventional 'big tank' model, where a thick column of residual magma is always present and new injections of magma are added progressively above previously crystallized cumulates, to an interpretation where most plutonic rocks, ultramafic-mafic and intermediate-felsic, are assembled by incremental accumulations of magma to produce composite intrusions in the Earth's crust.