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How can we construct timescales of pluton emplacement? The answer from high-precision U-Pb dating of the Adamello batholith

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High-precision U-Pb zircon geochronology has become an invaluable tool for calibrating the tempo of eruptive and intrusive igneous processes, quantifying volumes and rates of magma flux, degrees of liquid-crystal separation, and of magma mixing and crustal assimilation during fractionation. Age scatter of individual zircon and titanite grains suggests that plutons are assembled by the amalgamation of small pulses of magma, thus downplaying the importance of large magma chambers in the generation of batholiths, at least at middle to upper crustal levels. As a result of increased age precision beyond the 0.1% level in U-Pb CA-ID-TIMS geochronology of single- to sub-grain zircons, it is becoming increasingly common in plutonic rocks to find populations of zircons on the hand sample scale that record zircon growth over 10e4-10e6 years.

In order to use such spread of 206Pb/238U dates for reconstructing the crystallization history of a magmatic liquid we have to exclude lead loss from decay-damaged areas in zircon as a source of scatter, and establish tests for the success of the “chemical abrasion” technique prior to analysis. Pre-eruptive/pre-intrusive growth is found to be the main reason for scattered zircon ages in igneous rocks; a zircon date does not necessarily represent the age of the intrusion of a magma any more. Zircons crystallizing from the final magma batch are called autocrystic. Autocrystic growth will happen in a moving or stagnant magma shortly before or after the rheological lockup by the crystals. Last crystallizing zircons in the interstitial melt may therefore postdate emplacement of the magma. The range of 206Pb/238U ages may yield a time frame for the cooling of a given magma batch, which could be added to quantitative thermal models of magma emplacement and cooling. Trace element ratios (e.g., Th/U, Gd/Yb, Eu/Eu*) and initial Hf isotopes of the dated zircon volume are used to trace the nature of the dated grains, specifically for identification of crystals that form earlier at lower crustal levels (antecrysts). Autocrystic zircons may show, e.g., distinctly different (higher or lower) Th/U ratios. The range of zircons therefore contains a geochemical record of the liquids from which they crystallized which can potentially provide information about the geochemical evolution of a magmatic system with time.

The Adamello batholith in northern Italy is used as an example to demonstrate that very different timescales are involved in its construction: 10-12 Ma for the intrusion of the Adamello batholith, 1-2 Ma for the assembly of one pluton (such as the Re di Castello unit), 250-300 ka for the accretion of an intrusive suite (such as the Val Fredda or the Lago di Vacca suites), 20-40 ka for the crystallization and cooling below the solidus of an individual magma pulse. By applying our techniques we can trace the geochemical evolution of the magmas during crystallization of zircon, involving assimilation, fractional crystallization, and magma mixing processes, and resolve them temporally with high precision.