4DTHERM: Constraining thermal and exhumation histories of magmatic-hydrothermal systems using U-Pb and (U-Th)/He data

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We demonstrate the results of a computational model (4DTHERM) which combines (U-Th)/He thermochronometry and U-Pb geochronology data with numerical modeling techniques to quantitatively constrain the thermal and exhumation history of igneous intrusions and associated magmatic-hydrothermal ore deposits. The model considers various parameters related to the cooling of intrusive bodies (conduction cooling, latent heat of crystallization and fusion, thermal convection within magma bodies, hydrothermal circulation induced by magma intrusion, exhumation and erosion) and quantifies the thermal and exhumation history of a given igneous intrusion directly from measured geo-/thermochronometry data.

The complete thermal history of igneous bodies includes magmatic cooling and exhumation cooling. Numeric modeling indicates that the magmatic cooling of igneous bodies is complicated but can be further divided into two distinct stages. In the first stage the igneous body cools rapidly while the ambient country rock is simultaneously heated, and this stage is characterized by a very high cooling rate; during the second, longer duration cooling stage, both the igneous body and the ambient country rock cool slowly until they reach a final thermal equilibrium. The exhumation cooling stage is primarily controlled by erosion and exhumation processes. The cooling of igneous bodies is affected by many factors but intrusion size and emplacement depth are the principal controls on the cooling rate and the duration of the two magmatic cooling stages.

Combined models for magmatic and exhumation cooling provide a complete digitized thermal history curve which can then be constrained using apatite (U-Th)/He, zircon (U-Th)/He, and zircon U-Pb age data. The digitized temperature-age curve defines the time and depth of emplacement, crystallization age intervals for mineralised zones, cooling rate, "cooled" and exposure ages, and exhumation/erosion rate for the ore deposit. The validity of the curve generated by the inverse thermal modelling routine is demonstrated using age data from a number of porphyry copper deposits.

4DTHERM is implemented in Java programming language, is platform independent and is available to the research community as freeware.