

The link between U-Pb ages of accessory minerals and metamorphic conditions

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U-Pb geochronology has long suffered the difficulty of relating ages to metamorphic conditions and deformation. In fact, the U-Pb method mainly relies on accessory mineral (e.g. zircon and monazite), which behaviour and stability in metamorphic environments is not well known. Moreover, textural analysis of accessory minerals is generally of little significance.

The most direct way to relate U-Pb ages to metamorphic conditions are inclusions found in the dated mineral zone. Multiple generations of inclusions in zircon from the diamond facies gneisses of the Kokchetav massif combined with cathodoluminescence allowed the distinction of four zircon domains. Inclusions of key minerals such as coesite, diamond, garnet, feldspar and micas of variable composition, allowed relating the formation of the different domains to the evolving rock paragenesis and thus to specific metamorphic conditions.

Titanite is one of the few minerals datable by U-Pb whose thermodynamic properties, stability and role in metamorphic reactions are reasonably well known. Titanite from the Dora Maira ultra-high pressure unit retains four growth zones with different chemical (major and trace elements) and isotopic compositions. With the help of mineral inclusions and the modelling of mineral equilibria involving titanite, the ages obtained for the Alpine titanites were linked to three stages in the tectono-metamorphic evolution of the unit.

An additional and more general method to link U-Pb ages and petrology is based on the trace element composition of the dated mineral. The trace element composition of zircon varies according to the composition of coexisting minerals that incorporate the same trace elements found in zircon. The coexistence of zircon and feldspars is reflected in a negative Eu anomaly in the zircon REE pattern. The coexistence of garnet with zircon produces a systematic depletion of Y and HREE in the zircon. Through the experimentally determined equilibrium partitioning of trace elements between these two minerals, the formation of metamorphic zircon can be related to a specific garnet zone. Zircon ages can thus be linked to pressure and temperature conditions obtained from the garnet. Similar variations in trace element composition are under investigation in other U-bearing minerals such as titanite and monazite.

The combination of these techniques leads to the definition of detailed pressure-temperature-time paths that are the base for crucial geological and tectonic data, such as exhumation and subduction rates.

Mechanisms of metal-silicate equilibration in the terrestrial magma ocean

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It has been proposed that the high concentrations of moderately siderophile elements (e.g. Ni and Co) in the Earth's mantle are the result of metal-silicate equilibration at the base of a deep magma ocean that formed during Earth's accretion. According to this model, liquid metal ponds at the base of the magma ocean and, after equilibrating chemically with the overlying silicate liquid at 25-30 GPa, descends further as large diapirs to form the core. Here we investigate the kinetics of metal-silicate equilibration in order to test this model and place new constraints on processes of core formation. We investigate two models: (1) Reaction between a layer of segregated liquid metal and overlying silicate liquid at the base of a convecting magma ocean, as described above. (2) Reaction between dispersed metal droplets and silicate melt in a magma ocean. In the liquid-metal layer model, the convection velocity of the magma ocean controls both the equilibration rate and the rate at which the magma ocean cools. Results indicate that time scales of chemical equilibration are about 3 orders of magnitude longer than the time scales of cooling and crystallization of the magma ocean. In the falling metal droplet model, the droplet size and settling velocity are critical parameters that we determine from fluid dynamics. For likely silicate liquid viscosities, the stable droplet diameter is estimated to be about 1 cm with a settling velocity of about 0.5 m/s. Using such parameters, liquid metal droplets are predicted to equilibrate chemically after settling a distance of a few hundred meters. These models show that the concentrations of moderately siderophile elements in the mantle could be the result of chemical interaction between settling metal droplets and silicate liquid in a magma ocean but not between a segregated layer of liquid metal and overlying silicate liquid at the base of the magma ocean. Consequently, the depth of the magma ocean is unlikely to have corresponded to the apparent equilibration pressure of 25-30 GPa. Preliminary results of polybaric metal-silicate fractionation models show that the dynamics of silicate mixing during metal droplet fallout has a large effect on the apparent equilibration pressure.