Timing and scales of magmatic-hydrothermal processes: what we learned from the studies of porphyry-Cu-(Mo-Au) systems

Датиране и скорост на магмено-хидротермалните процеси: какво научихме от изследването на медно-(Mo-Au)-порфирните находища

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Introduction

The formation of ore deposits results from a chain of process, related to the interaction of lithosphere and crust, regional and local tectonics, magmatism and geochemistry, which eventually lead to fluid focusing and metal precipitation (Heinrich, C., unpublished lectures at ETH-Zurich). One important variable in these processes is the time. Apparently, the time influences the geochemistry and fertility of magma and magmatic-hydrothermal system (e.g., Chiaradia et al., 2013; Carrichi et al., 2014). Therefore, it is important to choose the most reliable methods, which will allow not only to date the ore-formation but also to distinguish the age of precipitation from that of the consequent overprinting processes. The timing and rates of processes of the most complex magmatic-hydrothermal porphyry systems, including porphyry-Cu, epithermal and skarn deposits, are objects of discussion for years. Here, we summarize the newest knowledge about the used methods and improvement of techniques and discuss them on the example of Elatsite porphyry-Cu deposit in the Upper Cretaceous magmatic and metallogenic belt in Bulgaria.

Timing approaches and isotope methods: choosing the right strategy

Deciphering of successive relatively “short” processes leading to the formation of (sometimes giant) deposits requires the application of reliable geochronological methods. Although the geological time is usually measured in Ka and Ma an important aspect in the understanding of the complex deposit models is the precise timing of the distinct processes of magma generation, accumulation of water and metals, fluid focusing and metal precipitation. There are different approaches of deposit dating and all they start with field studies of the temporal successions, which are documented in the cross-cutting relationships of host and igneous rocks, dykes, ore veins, inclusions of rocks and minerals. The absolute dating of ore-formation is based on: (i) isotope dating of ore minerals, e.g., molybdenite (Re-Os method); (ii) absolute dating of hydrothermal minerals of the alteration zones (e.g., KFs/adularia, biotite, white micas with Ar-Ar or Rb-Sr method; hydrothermal rutile, titanite and other U-bearing minerals with U-Pb isotope method); (iii) dating of magmatic events (pre-, syn- and post-ore) that bracket the ore deposition with U-Pb CA-ID-TIMS (CA – chemical abrasion) zircon method. In the last 5 years the latter was improved in all its aspects – pretreatment of zircons, lowering of Pb-U blank, correction for fractionation and different effects during the TIMS analyses to reach an “unprecedental” <0.1 to 0.01% precision. LA-ICP-MS techniques is used to roughly define the age, and then the concordant autocrysts are taken out of the epoxy mount, CA-treated and dated with the precise CA-ID-TIMS.

The ore deposits are usually structurally controlled. Tectonics is also crucial for the preservation of the shallow porphyry-copper deposits (PCDs). To date the faults or define the time of exhumation we apply low temperature dating techniques, as Ar-Ar and Rb-Sr on potassium rich minerals and of FT (fission track) and (U-Th)/He thermochronology on zircon, apatite and titanite.

Deposit to regional scale rates of PCD

The three minerals and isotope methods that generate results with the highest precision and accuracy for dating a magmatic-related hydrothermal system are U/Pb on zircon, Re/Os on molybdenite and $^{40}Ar/^{39}Ar$ on potassium-rich minerals. The high precision of dating helps distinguishing clusters of deposits, rather than one porphyry system. New precise CA-ID-TIMS U-Pb zircon age data from young magmatic-hydrothermal systems (with lower absolute uncertainties) are in agreement with ore-formation period reported from numeric modelling of porphyry systems between ~100 and 5000 yrs (e.g., Weiss et al., 2012). In the case of multiple intrusions, the magmatic-hydrothermal system might be recharged, reheated and revived but precise dating argues again for a life-span of 6000 yrs (one magmatic impulse) to <29 000 yrs of the whole dyke succession (e.g., Bajo de la Alumbrera, Argentina – Buret et al., 2016). Longer deposit formation period of up to 1.0–2.0 Ma is supported by multiple intrusions and assumed for the giant El Teniente porphyry-copper system (summary of Chiaradia et al., 2013). In other cases, longer life-times are ascribed to $^{40}Ar/^{39}Ar$ or Rb-Sr dating of alteration minerals. Unfortunately, some potassium rich minerals as white mica may crystallize not only from circulating fluids during the cooling of the main magmatic-hydrothermal system but also during later overprinting processes.

On region scale, ore-related magmatism lasts from 10–14 to over 30 Ma. These scales allow the application of less precise methods, as U-Pb LA-ICP-MS zircon techniques for linking the ore mineralization to specific time periods.

Elatsite porphyry system

Recent application of the high-precision CA-ID-TIMS U-Pb zircon method helped refining the age of porphyry and aplitic dykes that bracket the time of porphyry Cu-(Mo-Au) deposit formation in Elatsite PCD. From our new age data, the main mineralization is confined by the individually dated igneous events between 92.329±0.021 Ma and 92.050±0.019 Ma, thus the entire time span for ore-forming magmatism and high-temperature hydrothermal activity extended over a maximum duration of 0.31 Ma. In Elatsite a thermal anomaly at ~81 Ma is suggested by the new FT and (U-Th)/He dating of zircons, similar to published Ar/Ar sericite age of 79.9±1.4 Ma (Lips et al., 2004). These ages differ substantially from the Re/Os molybdenite ages (92.4±0.3 to 91.88±0.5 Ma), from Ar/Ar and Rb/Sr ages of minerals with higher blocking temperature than sericite such as amphiboles, and the biotite and K-feldspar from the potassic alteration assemblage (91.7±1.4 Ma to 90.55±0.8 Ma). Therefore, we can conclude that most probably the main magmatic-hydrothermal activities ceased at ~90–91 Ma, whereas ascription of ages ~80 Ma to distinct magmatic and/or hydrothermal event needs further detailed studies.

Strontium isotope system in the magmatic-hydrothermal system of Elatsite is altered due to magmatic and fluid-rock interaction. Our data revealed this system as one of the most susceptible to thermal- and fluid-caused diffusion and resetting. Reliable dating by Rb/Sr method will be possible only by accurate separation of mineral associations and unaltered rocks.

The majority of the world-class porphyry-Cu deposits are Cenozoic. The preservation of the Upper Cretaceous Elatsite deposit might be explained by the Paleocene–Eocene compression in the Balkan belt that lead to the tectonic burial and consequent preservation of the deposits. In Late Eocene–Oligocene time (U-Th/He apatite ages of 39.3±3.0 Ma) the region was cooled down to temperatures below 75 °C and afterward exhumed to the surface uncovering the 3–4 km deep porphyry system.

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