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How long does it take to make a giant porphyry copper deposit? Advances in high-precision geochronology and modelling of magmatic-hydrothermal processes

Колко време отнема да се формира гигантско медно-порфирно находище? Напредък в прецизната геохронология и моделирането на магматично-хидротермални процеси

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Porphyry copper deposits are characterized by multiple phases of magma emplacement alternating with hydrothermal veining, alteration and copper deposition. This geological complexity has contributed to the notion that the formation of the best deposits is a complex process drawn out over an extended time period. Combining the most precise geochronological constraints with microchemical evidence from zircon concur with physical models that the formation of even the biggest deposits is a rapid process lasting a few 10 000 years.

A workflow of field documentation, zircon petrography using SEM-CL imaging, LA-ICPMS microchemistry including Hf isotopes, and final recovery of the same crystals for chemical-abrasion isotope-dilution thermal-ionization mass spectrometry (CA-ID-TIMS) provides time-calibrated information about the evolution of mineralizing magma chambers. These data may be complemented by Re-Os geochronology of molybdenite, whereas in-situ LA-ICPMS U-Pb geochronology and Ar-Ar dating are useful for regional age determination but not for measuring the duration of deposit formation.

Results are consistent with the interpretation that a single upper-crustal magma reservoir at 5–10 km depth acts as the source of fluid making one ore deposit. Antecrysts with geochemical signatures recording upper-crustal fractionation indicate life-times of large crystallizing magma chambers in the upper crust lasting several 100 000 years. 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 FT (fission track) and (U-Th)/He thermochronology on zircon, apatite and titanite.

Magma flux rate from the mantle or lower crust must be high enough to fill an upper-crustal magma reservoir of adequate size, but slow enough to prevent surface eruption. Injection of mafic magma into a crystallising magma chamber extends its thermal lifetime and adds to its volatile budget, and one final injection event may trigger the onset of large-scale fluid saturation and porphyry copper ore formation. However, there is no convincing evidence that repeated re-filling or multiple rejuvenation events in the magma chamber caused successive fluid pulses contributing to gradual build-up of a porphyry orebody.

Several Cu-porphyry targets (Fig. 1) have been selected, four of Miocene to Pleistocene age (Ok Tedi, PNP – Large et al., 2018; Koloula, Solomon Island – Tapster et al., 2016; Batu Hijau, Indonesia; Bajo de la Alumbrera, Argentina – Buret et al., 2016, 2017) and one of Cretaceous age (Elatsite, Bulgaria). High-precision zircon geochronology and physical modelling concur that this process extends over 10 000 to 100 000 years, for world-class to giant ore deposits.

In summary, economic porphyry copper deposits are not assisted by complexity or by extended duration of superimposed processes. Rather, the largest and richest deposits result from fine-tuning the balance of concurrent processes of fluid production, fluid focusing and heat transfer from the magmatic fluid plume to convecting meteoric water.

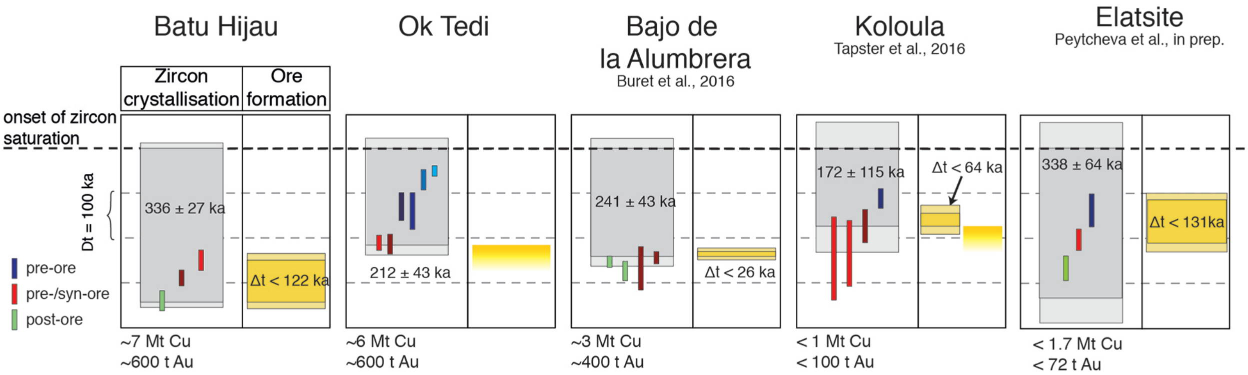

Fig. 1. Summary of U-Pb zircon CA-ID-TIMS age data for porphyry copper deposits of different size: Batu Hijau (Indonesia), Ok Tedi (Papua New Guinea, Large et al., 2018), Bajo de la Alumbrera (Argentina), Koloula (Solomon Island) and Elatsite (Bulgaria)

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