SEG 2017 Conference

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

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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. Five conclusions are contrasted here vis-a-vis current practice and published opinions.

(1) 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.

(2) 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 cystallizing magma chambers in the upper crust lasting several 100’000 years.

(3) Magma flux rate from the mantle or lower crust must be high enough to fill an upper-crustal magma reservoir of adequeate size, but slow enough to prevent surface eruption. Apart from the mass-balance constraint that larger deposits require larger magma chambers, there is no convincing empirical correlation between flux rate and deposit size.

(4) 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, porphyry copper ore formation, and possibly terminal volcanic eruption. However, there is no convincing evidence that multiple rejuvenation events in the magma chamber caused successive fluid pulses contributing to gradual build-up of a porphyry orebody, with intermittent cooling to ambient crustal temperature between mineralization pulses.

(5) The first event of water saturation in this magma chamber is most effective regarding the quantitiy of ore fluid production. It generates a single-phase mildly saline fluid transporting Fe, Cu and S together towards the site of Cu-Fe-sulfide deposition. The rate of magmatic fluid production is controlled by heat loss of this magma chamber to the upper crust and to convecting surface fluids, and by the enhanced permeability of a crystal mush for magmatic fluid release

compared to fluid bubbles rising in a melt-dominated magma. High-precision zircon geochronology and physical modeling 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 focussing and heat transfer from the magmatic fluid plume to convecting meteoric water.