Duration of ore formation: Grasberg porphyry copper deposit, Papua, Indonesia

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Isotopic dating of intrusions and hydrothermal alteration from porphyry copper deposits worldwide is rarely able to constrain the duration of ore formation with a resolution better than one million years. Zircon U/Pb dating of intrusions that host and cross-cut ore grade mineralization at the supergiant Grasberg deposit, located in Papua, Indonesia, provides a constraint on the maximum duration of hydrothermal fluid flow. Porphyry copper-type mineralization is hosted in the Grasberg Igneous Complex (GIC), which comprises three pulses of magmatism: the Dalam Phase, the Main Grasberg Intrusion (MGI), and the Kali Dikes. Main phase copper mineralization initiated following intrusion of the MGI (3.07±0.05 Ma, n=107) and predates the Late Kali Dike (2.99±0.05 Ma, n=90). Based on these ages the Grasberg deposit formed in less than 180 k.y, and perhaps less than 80 k.y. The oldest intrusion dated in the Ertsberg-Grasberg district is the Wanagon Sill (3.43±0.07 Ma, n=52) and the youngest intrusion is a dike cutting the Ertsberg pluton (2.71±0.07 Ma, n=32). These data constrain the duration of magmatism in the district to less than 900k.y.

Apatite and zircon (U-Th)/He (aHe and ZHe) ages provide additional insight into the low-temperature thermal history associated with ore formation. Samples were collected from a vertical profile in the Kali Dikes spanning 2 km. Near-surface samples cooled almost immediately following crystallization (3.1±0.2 Ma zHe age), whereas samples at 2 km depth cooled more slowly (2.1±0.3 Ma zHe age). Throughout the vertical profile aHe ages are less 0.6 m.y. younger than the than the zHe ages. Based on these ages the calculated cooling rate from 750-180°C was 150°C/10 k.y. near the surface, 11°C/10 k.y. at 1 km depth, and 4°C/k.y. at 2 km depth. The cooling rate from 180-70°C was 11°C/k.y. Collectively these results indicate Grasberg ore formation occurred immediately following MGI emplacement, was short-lived, and the system rapidly cooled. The high cooling rates to temperatures below 70°C at 2 km depth indicate the wall rock was cold and preclude the presence of a 2 km tall volcanic structure over the orebody. High cooling rates and steep thermal gradients along the edges of the stock would cause rapid deep-seated crystallization of quartz and feldspars. This led to the formation of copper-rich fluid bubbles in mobile magma that rose to collect beneath a cupola before ascending to form the Grasberg orebody.