Colloidal Flocculation and the Mechanical Transport of Gold: Causes of the 'Nugget Effect' in Hydrothermal Ore Deposits

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The nugget effect, a phenomenon that results in a strong skewing of the precious metal distribution in vein-hosted hydrothermal systems towards spatially discrete occurrences, or nuggets, poses a major challenge for exploring, modelling, and mining many types of ores. Although researchers have long investigated ways to mitigate the products of the nugget effect, namely the extraordinary grade variability seen in many bonanza-type deposits, relatively little progress has been made in explaining its fundamental causes. Recent recognition of the role that the mechanical transport and flocculation of metallic nanoparticles plays in the genesis of high-grade hydrothermal gold deposits, however, offers new insight into the formation of very coarse grained or nuggety gold. Here, we present a synthesis of nano- to micro-scale textural and chemical TEM observations from the Brucejack bonanza-type epithermal Au-Ag deposit in northwestern British Columbia, Canada. These observations demonstrate that flocculation (i.e., aggregation) of gold nanoparticles suspended in the ore fluid formed spectacularly high-grade (e.g., up to 42,100 g/t Au over 0.5 m core intervals) yet highly discontinuous, nuggety mineralization. We go on to show, using data from EMPA, high-resolution in situ SIMS, and LA-ICP-MS analyses of pre- to syn-mineralisation pyrite, that three distinct processes operated on gold transported as a colloid (i.e., a suspension of negatively-charged nanoparticles in an electrolyte solution). These processes drove flocculation through: (1) the electrochemical destabilisation of colloids by interaction with semiconductive p-type arsenian pyrite; (2) surface-charge-bridging of colloids by cationic flocculants added to the ore fluid through mixing with seawater; and (3) cooling of the ore fluid by boiling and/or seawater mixing. We conclude that these processes, which are common in many near-surface hydrothermal systems, can account for the genesis of nuggety gold in many hydrothermal deposit types and, by extension, help predict their occurrence at the deposit scale.