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Multiple Sulfur Isotope and Trace Element Analysis of Pyrite in the Kanowna Belle Deposit, Western Australia: Insights into Fluid Oxidation and Gold Precipitation Processes

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In orogenic gold deposits, the processes by which gold is precipitated from hydrothermal fluids to form Au-rich veins remain controversial. Textural observations and geochemical analyses on orogenic gold deposits have come up with different interpretations on how gold is precipitated, such as fluid mixing, fluid-rock interaction, wall-rock carbonation, and/or phase separation (boiling). The Kanowna Belle deposit hosts gold mineralization in quartz-pyrite-gold veins hosted in volcano-sedimentary and granitic rocks of the Kalgoorlie Terrane, Australia. Pyrite hosted in the gold-rich veins demonstrates evidence of three phases of growth zoning (Pyrite core, mantle, and rim). Using in-situ multiple sulfur isotopes and trace element geochemistry coupled with vein paragenesis, we monitor different phases of hydrothermal fluid evolution, including the critical phase when gold precipitation occurs. Results show that the pyrite core is Au-poor (Au ≤149 ppm), with moderate As (≤2.5 wt %) and Te content (≤416 ppm) and elevated Ni contents (≤4,022 ppm). Pyrite mantle is Au-rich (≤2,251 ppm) with high As (≤4.5 wt %) and Te (≤829 ppm) content and lower Ni (≤1,111 ppm) content. The late pyrite-rim are Au- (≤264 ppm) and As- (<1.4 wt %) poor, with low Te (≤229 ppm) and Ni (≤2113 ppm) contents. The sulfur isotope composition of the pyrite comprises heavier and more constrained values in the pyrite core ($\delta^{34}S$ = -3.3 to +4.2‰), followed by a lighter range with wider variation in the pyrite mantle ($\delta^{34}S$ = -8.4 to +0.1‰), and a heavier range in the pyrite rim ($\delta^{34}S$ = -6.0 to +2.8‰). Importantly, each pyrite zone preserves consistent $\Delta^{33}S$ values of $\Delta^{33}S$ = +0.3 ± 0.2‰, indicating a single sulfur reservoir was retained during the whole pyrite precipitation process. Therefore, the changes of trace element contents and $\delta^{34}S$ content within the pyrite growth zones should be related to fluctuations of fluid oxidation and pressure conditions. Gold-rich pyrite is precipitated during fluctuations of SO_4^{2-}/H_2S conditions associated with phase separation induced by a rapid drop of fluid pressure during the "fault-valve" process. Our findings demonstrated that the "fault-valve" is an important process in precipitating gold from a single Au-rich fluid reservoir and is an integral process for the formation of Orogenic gold deposits.