SEG 2017 Conference

Ore-forming process in the Heilan'gou gold deposit, Jiaodong Peninsula, China: Constraints from elemental mapping and in situ sulfur isotopic analysis of pyrite

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The Jiaodong gold province, one of the largest gold producers in the world, is located in the jiaodong peninsula in the eastern margin of the North China Craton (NCC). The Heilan'gou gold deposit, hosted by Mesozoic granodiorites in the central part of the Jiaodong gold province, is characterized by the development of high grade auriferous quartz veins (Linglong-type).

Based on veins cross-cutting relationships and detailed microscopic observations, fourmineralizationstages have beendistinguished from early to late, namely (1) white barren quartz vein stage(pre-ore stage), (2) gold-quartz-pyrite vein stage, (3) gold-quartz-polymetallic sulfides vein stage, and (4) quartz-carbonate vein stage(post-ore stage). The 2nd and third mineralizationstages are intensively developed in the deposit, during which the majority of goldin the deposit were precipitated.

Petrography (BSE)and compositional mapping of pyriteshow a clear paragenetic succession for various types of hydrothermal pyrites, as well as for their relationship to other sulfides and gold. No-zoned Py-I is the only dominant ore mineral in the quartz-pyrite veins (Stage 2) and is characterized by a low As, Au and $\delta^{34}S$ value, with less amount visible gold in fractures. This indicates initial hydrothermal fluids would have not contained enough amount of gold and other trace elements. In quartz-polymetallic sulfides vein(Stage 3), Py-II is commonly composed of As-free core (Py-IIa) and As-richcompositionally zoned rim(Py-IIb). The earlier Py-IIa shows a roughly similar geochemical features to Py-I, but with much more fined galena inclusions andcoexisting other sulfides. In contrast, the later Py-IIb has distinct Au and As enrichmentand comparatively higher $\delta^{34}S$ value. And Py-IIb shows either As oscillatory growth zonation or heterogeneous domains, with abundant Au-Ag-As-Te-Cu-Pb mineral inclusions.

Nano-SIMS trace elemental mappingof Py-IIa(core) and Py-IIb(rim) clearly reveal As–S negative correlation and As-Au positive correlation. Combined with the abundant micro-sized mineral inclusions in As-Au-rich Py-IIb, it's reasonable to presume that Au in Py-IIb occurs as both solid solution (Au^{+1}) and nanoparticles of gold (Au^{0}) together. The sharp textural and compositional boundaries between cores and rims and difference in mineral inclusions suggestthat the Py-IIb and related abundant gold were possibly precipitated from an episodic pumping anomalous As-Au-rich fluids, rather than from thefluids responsible for the deposition of the earlier barren pyrites.

It is worth noting that the$\delta^{34}S$ valuesof Py-IIb is slightly higher than earlier Py-I and Py-IIa. Previous fluid inclusion studies of quartz vein deposits have shown that precipitation of gold is possibly a consequence of phase separation in response to seismic pressure fluctuations(Hou et al., 2007; Wen et al., 2015), leading to the above-mentionedmultiple ore mineral deposition. Consequently, phase separation can release a certain amount of H_2S into the vapor phase, which

not only decreases the stability of Au–S complexes, but makes higher $\delta^{34}S$ values of pyrite precipitated from the fluid solution.