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Texture, geochemistry, and geochronology of titanite and pyrite: Fingerprint of magmatic-hydrothermal fertile fluids in the Jiaodong Au province

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Abstract

The Au mineralization in the giant Jiaodong Au province is enigmatic and difficult to fit current classic mineralization models, primarily because of uncertainties as to the sources of ore-forming fluids and metals. The ca. 120 Ma Au mineralization has been previously proposed to have occurred during a magmatic lull, which would negate a magmatic-hydrothermal genetic model. However, recent drilling has revealed a buried mineralized monzonite equivalent in age to the Au mineralization in the Linglong goldfield. Here, we present comprehensive textural, geochemical [LA-(MC)-ICP-MS trace element, Nd and S isotopes] and geochronological (LA-ICP-MS U-Pb dating) analyses of titanite and pyrite from this previously unrecognized monzonite. Three types of titanite were distinguished, including magmatic Ttn1 and hydrothermal Ttn2 and Ttn3, which show indistinguishable U-Pb ages (120.7 ± 3.1 and 120.9 ± 2.6 Ma), REE patterns and Nd isotopes [$\varepsilon_{Nd}(t)$ = –14.7 to –12.9], implying that hydrothermal fluids were directly exsolved from the monzonitic magma, contemporaneous with the large-scale Au mineralization at ca. 120 Ma. The Nd isotopes of titanite potentially indicate a lower crustal source mixed with mantle materials for the monzonite. Four types of pyrite were analyzed, including magmatic Py1 from fresh biotite monzonite, hydrothermal Py2 from altered biotite monzonite, hydrothermal Py3 from quartz-pyrite veins with a monazite U-Pb age of 118.2 ± 4.6 Ma, and magmatic Py4 from mafic enclaves of the Gushan granite at ca.120 Ma. The $\delta^{34}S$ values of magmatic Py1 and Py4 (+1.9 to +6.3‰, and +5.0 to +6.4‰, respectively) and hydrothermal Py2 and Py3 (+6.4 to +9.5‰ and +6.5 to +7.6‰, respectively) are consistent with sulfur isotopic fractionation between melt and fluid. Hydrothermal Py2 and Py3 also have higher Co, As, Ag, Sb, and Bi contents and submicrometer gold inclusions, implying that the magmatic-hydrothermal fluids were fertile for mineralization. This study highlights the importance of monzonite magmatism and exsolved fertile fluids in regional Au mineralization. Hydrous magmas at ca.120 Ma probably extracted Au efficiently from the lower crustal-mantle sources and released auriferous fluids at the late magmatic stage, leading to the formation of Au deposits in the Jiaodong province.

Keywords: Titanite, pyrite, monazite, biotite monzonite, U-Pb geochronology, magmatic-hydrothermal fluid