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## Supplemental Material

### **Supplemental Material 1.** Analytical Methods

### **Supplemental Material 2.** Analytical Data

**Table S1.** LA-ICP-MS zircon U-Pb isotope data of ore-hosting metamorphic rocks of the Shuangqishan gold deposit.

**Table S2.** LA-ICP-MS U-Th-Pb isotope data for zircon grains from the diorite and granite porphyry dikes in the Shuangqishan gold deposit.

**Table S3.** LA-ICP-MS apatite (Ap1 and Ap2) U-Th-Pb data of metamorphic and auriferous quartz veins from the Shuangqishan gold deposit.

**Table S4.** Trace-element compositions of multiple-generation apatite from the Shuangqishan gold deposit, analyzed by LA-ICP-MS.

**Table S5.** *In situ* Sr isotope compositions of multiple-generation apatite from the Shuangqishan gold deposit, analyzed by LA-MC-ICP-MS.

**Table S6.** Electron microprobe geochemical data for hydrothermal xenotime crystals from the Shuangqishan gold deposit.

**Table S7.** SHRIMP U-Th-Pb isotope data for hydrothermal xenotime from the sub-stage IIb gold ores in the Shuangqishan gold deposit.

## SUPPLEMENTARY MATERIAL 1: ANALYTICAL METHODS

### ***Optical cathodoluminescence microscopy***

Optical cold CL photomicrography was performed on polished thin sections containing apatite grains using an Olympus microscope attached to a RELIOTRON III CL stage housed at the State Key Laboratory of Geological Processes and Mineral Resources, China University of Geosciences, Wuhan (GPMR-CUG). The low-vacuum Relion system was set to an electron source operated at 15 to 20 kV and about 500 to 800  $\mu\text{A}$ .

### ***Zircon U-Pb dating***

Using cathodoluminescence (CL) and transmitted and reflected light micrographs, suitable zircon grains were selected for further analysis. Zircon U-Pb dating analysis was performed by LA-ICP-MS housed at the GPMR-CUG, using an ArF excimer laser system (GeoLas Pro, 193-nm wavelength) and a quadrupole ICP-MS (Thermo iCap). The analyses were carried out with a pulse rate of 10 Hz, beam energy of 10  $\text{J}/\text{cm}^2$ , and a spot diameter of 32  $\mu\text{m}$ . NIST 612 was analyzed once for every eight analyses of the tested sample. The zircon U-Pb ratio was corrected by using zircon 91500 ([Wiedenbeck et al., 1995](#)) as an external standard. The U-Pb ages were processed by ICPMSDataCal 9.7 program ([Liu et al., 2008](#)), and calculation of U-Pb ages was carried out using the Isoplot-3 software ([Ludwig, 2003](#)).

### ***LA-ICP-MS apatite U-Pb dating***

*In-situ* U-Pb isotope analyses of apatite were carried out using the same instrumental configuration as described earlier for zircon U-Pb dating. The laser was set at 8-Hz repetition rate and 5  $\text{J}/\text{cm}^2$  energy density with 60  $\mu\text{m}$  spot size. The MAD apatite standard was used as the matrix-matched standard to correct the U-Pb fractionation and the instrumental mass discrimination

(485 Ma; Thomson et al., 2012). Tera-Wasserburg diagrams were constructed using Isoplot-3 (Ludwig, 2003), with 95% confidence in accuracy. The upper intercept represents the initial  $^{207}\text{Pb}/^{206}\text{Pb}$  ratios, which were used for common Pb correction to obtain relatively precise  $^{206}\text{Pb}/^{238}\text{U}$  ages (Chen and Simonetti, 2013).

### ***SHRIMP U-Pb dating of xenotime***

Xenotime grains of sufficient size ( $>20\text{ }\mu\text{m}$  in diameter) were drilled out from the polished thin sections of auriferous pyrite-rich vein material into  $\sim 2\text{ mm}$  plugs and then cast into 25 mm epoxy mount along with standards. The mount was analyzed using the SHRIMP-II housed at the Research School of Earth Sciences, Australian National University. Optical and BSE images were used to guide the placement of the primary ion beam during SHRIMP analyses. Analytical procedures and operational settings were similar to those described in Cross and Williams (2018). The SHRIMP U-Th-Pb data were reduced with the Squid-2 software (Ludwig, 2012) using spot average values for all ratios. Xenotime MG-1 (490 Ma; Fletcher et al., 2004) and BS-1 (509 Ma; Aleinikoff et al., 2012) were used as primary standards for the calculation of Pb/U and Pb/Th ages. The U and Th abundances used in matrix corrections were derived from the SHRIMP data. The REE abundances used in matrix corrections for xenotime are from electron microprobe analyses made adjacent to SHRIMP analytical spots. Data plots were prepared using Isoplot-3 (Ludwig, 2003). Individual analyses are presented with  $1\sigma$  errors, whereas weighted mean dates are quoted with 95% confidence limits.

### ***LA-ICP-MS trace element analysis of apatite***

*In-situ* LA-ICP-MS trace element analyses of apatite were conducted using the same instrument configuration described earlier for U-Pb apatite dating. International standards NIST 610 and NIST

612 were used to correct signal drift, and the international glass standards NIST BCR-2G, BHVO-2G, and BIR-1G were used as external standards. Spot ablations were carried out using a 33  $\mu\text{m}$  spot size at 3  $\text{J}/\text{cm}^2$  and 10 Hz, with a 35 s baseline and 40 s of ablation. The detection limits were calculated for each element in each spot analysis. Off-line data processing was performed using ICPMSDataCal 9.7 software ([Liu et al. 2008](#)). The analytical uncertainties were generally lower than 10% (relative) for most trace elements.

### ***In-situ apatite Sr isotope analysis***

*In-situ* Sr isotope analysis of apatite spots was obtained by the same laser ablation system coupled to a Nu Plasma MC-ICP-MS housed at GPMR-CUG. The analytical protocol followed the method described by [Ramos et al. \(2004\)](#) and was fully described by [Chen et al. \(2018\)](#). The samples were analyzed using a 50 to 90  $\mu\text{m}$  spot size and a 10 Hz repetition rate. The Sr isotopic data were acquired by static multi-collection in low-resolution mode using nine Faraday collectors. During measurements, critical spectral interferences were systematically monitored, including Kr, Rb, and doubly charged REE, as outlined by [Ramos et al. \(2004\)](#). The natural ratio of  $^{85}\text{Rb}/^{87}\text{Rb}$  (2.593) was used for correction of isobaric Rb interference by the exponential law, assuming that Rb has the same mass discrimination as Sr. The in-house apatite standards Durango and MAD, and a modern-day Coral (Qingdao, China) standard were used to evaluate the analytical accuracy and the potential matrix-matched effect during analyses ([Yang et al., 2014](#); [Chen et al., 2018](#)).

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