

Appendix-1

Analytical methods

In situ quartz trace element analysis

SEM-CL images were obtained using a JSM7800F SEM equipped with a Mono CL4 detector. An acceleration voltage of 10kV, a probe current of ~10 nA, and a magnification of 200× were used for most images. Such high magnifications are required by this CL detector, which simultaneously collects SE and BSE images along with color CL images. Due to the small field of view, most images presented here are mosaics of multiple CL images digitally stitched together after acquisition.

Quartz in situ trace element analyses by LA-ICPMS were conducted on quartz samples selected from the two representative disseminated ores. CL imaging was undertaken to examine growth patterns and to distinguish different growth zones of the crystals. Analysis was conducted at the State Key Laboratory of Ore Deposit Geochemistry, Institute of Geochemistry, Chinese Academy of Sciences using an Agilent 7900 ICP-MS equipped with a GeoLasPro 193 nm ArF excimer laser. A laser repetition of 10 Hz and energy density of 10 J/cm² were used during the analyses. A laser spot size of 40 μm was used for the quartz trace element analysis. For quartz trace element calibrations, external standard NIST SRM 610 was used and analyzed twice

every 10 points. An internal standard-in-dependent calibration strategy, which is based on the normalization of the sum of all metal oxides to 100 wt. %, was applied to the quantitative calibrations using the ICP-MS DataCal software (Liu et al. 2008). This strategy has been proven to work well for anhydrous minerals (Liu et al. 2008). Standard glasses NIST SRM 612 and GSE-1G were analyzed to monitor the accuracy of the results. Results show that the uncertainties on Li, Na, Al, K, Ti and Ge measurements are less than 6%. Details of the LA-ICPMS in situ trace element analysis and instrument are described in Lan et al. (2018).

Bulk S isotope analysis

Bulk S isotopic compositions were analyzed using a Finnigan MAT-253 mass spectrometer at the State Key Laboratory of Ore Deposit Geochemistry, Institute of Geochemistry, Chinese Academy of Sciences. Powders of sulfide separates finer than 200 meshes were mixed with copper oxide (CuO) powder, and then heated to extract SO₂ gas. The ³⁴S/³²S ratios are expressed by the conventional δ³⁴S value notation in per mil (‰) relative to the Vienna Canyon Diablo Troilite (V-CDT) standard. The analytical error was better than 0.1‰ (1σ) calculated from replicate analyses of the IAEA international standards: IAEA S1 (-0.3‰), IAEA S2 (+22.62‰) and IAEA S3 (-32.49‰). The precision calculated from replicated analysis of unknown samples was better than 0.2‰ (2σ).

In situ S isotope analysis

In situ isotopic compositions were acquired on a CAMECA NanoSIMS 50 L at the Key Laboratory of Earth and Planetary Physics, Institute of Geology and Geophysics, Chinese Academy of Sciences. The measurements were made using three different settings of the Faraday cup (FC) and/or electron multiplier (EM) detector, which satisfy different requirements for spatial resolution. The effect of EM aging and quasi-simultaneous arrival was corrected before the calibration of instrumental mass fractionation by a standard-sample-standard bracketing method using the standards measured together with the samples. The standards used in this study include Balmat (pyrite and sphalerite), PY-1117 (pyrite), and MY09-12 (sphalerite). The analytical precision calculated from replicated analysis of unknown samples is better than 0.2‰ (1s). Details of the NanoSIMS in situ S isotope method and instrument are described in Zhang et al. (2014).

In situ Pb isotope analysis

In situ Pb isotopic ratios were measured using a Nu II MC-ICP-MS (Nu Instruments, Wrexham, UK) combined with a 193 nm RESOLUTION M-50 femtosecond (fs) laser ablation system (ASI) at the State Key Laboratory of Continental Dynamics, Northwest University, China. Line scan ablations consisted of 30s background collection followed by 50 s of laser ablation signal collection. Laser ablation parameters were as follows: (i) spot size: 15 μm for galena; (ii) energy density: 6 J/cm²; (iii) laser frequency: 5 Hz. The NIST SRM

997 20 ppb (TI, $^{205}\text{Ti}/^{203}\text{Ti} = 2.3889$) and NIST SRM 610 glass served as internal and external standards, respectively. Repeated analyses of NIST SRM 610 glass standard yielded highly reliable and reproducible results during the entire analytical session with mean $^{206}\text{Pb}/^{204}\text{Pb}$, $^{207}\text{Pb}/^{204}\text{Pb}$ and $^{208}\text{Pb}/^{204}\text{Pb}$ ratios of 17.052 ± 0.003 , 15.515 ± 0.003 and 36.980 ± 0.007 (1 SD, $n = 183$), respectively. Details of the fs LA-MC-ICP-MS in situ Pb isotope method and instrument set-up are described in Bao et al. (2016).

References

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