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## Supplemental Material

### **Supplementary Materials I: Figures S1 to S3**

**Figure S1.** Representative cathodoluminescence images of zircon grains from the biotite granites, granite porphyry dykes and MMEs.

**Figure S2.** Major oxide versus loss on ignition (LOI) diagram for the granite porphyry dykes.

**Figure S3.** Sn versus Rb/Sr diagram for the biotite granites and granite porphyry dykes.

### **Supplementary Materials II: Tables S1 to S7**

**Table S1.** Information about selected samples.

**Table S2.** LA-ICP-MS zircon U–Pb data for the biotite granites, granite porphyry dykes and MMEs.

**Table S3.** LA-ICP-MS zircon trace element compositions (ppm).

**Table S4.** Representative electron microprobe analyses of feldspar from the biotite granites, granite porphyry dykes and MMEs.

**Table S5.** Representative electron microprobe analyses and structural formula of biotite from the biotite granites and granite porphyry dykes.

**Table S6.** Whole-rock Sr-Nd isotopic data for the biotite granites, granite porphyry dykes and MMEs.

**Table S7.** In situ zircon Hf and O isotopic data for the biotite granites, granite porphyry dykes and MMEs.

### **Supplementary Materials III: Methodology**

#### **1. Zircon O isotopes**

Zircon grains were separated from crushed rock using a combination of heavy liquid and magnetic techniques. Representative zircon grains were handpicked under a binocular microscope, mounted in epoxy resin, and polished down to near half sections to expose the internal structures. An optical microscope was used to image these zircon grains under transmitted and reflected light. Cathodoluminescence images (Fig. S1) were taken using a Zeiss

Supra 55 field emission SEM equipped with a MonoCL4 cathodoluminescence detector. These images were used as guides to target the spot analyses for trace elemental and isotopic measurements.

Zircon oxygen isotopic analyses were carried out with a Cameca IMS-1280 ion microprobe. The  $^{133}\text{Cs}^+$  primary ion beam was accelerated at 10 kV, with an intensity of ca. 2 nA, and rastered a 20- $\mu\text{m}$  domain. A normal incidence electron flood gun was used to compensate for sample charging during analysis. Oxygen isotopes ( $^{16}\text{O}$  and  $^{18}\text{O}$ ), were determined simultaneously using multi-collection mode. Measured  $^{18}\text{O}/^{16}\text{O}$  ratios were normalized by Vienna Standard Mean Ocean Water (VSMOW,  $^{18}\text{O}/^{16}\text{O} = 0.0020052$ ), and then corrected for instrumental mass fractionation using the Penglai zircon standard ( $\delta^{18}\text{O} = 5.31 \pm 0.10$  ‰, Li et al., 2010). Detailed analytical procedures were similar to those described by Li et al. (2010). The internal precision of  $^{18}\text{O}/^{16}\text{O}$  ratio for a single analysis was generally better than 0.2 ‰ (1 $\sigma$  standard error). The Qinghu zircon, used as the unknown sample, yielded a weighted average  $\delta^{18}\text{O}$  value of  $5.43 \pm 0.23$  ‰ (2 $\sigma$ ) which is identical to the recommended value within analytical errors ( $5.4 \pm 0.2$  ‰, Li et al., 2013).

## 2. Zircon U–Pb ages and trace elements

U–Pb isotopic and trace elemental analyses of zircon were performed using an Agilent 7900 ICP-MS coupled with a Resonetics RESolution S-155 ArF-Excimer laser ( $\lambda = 193$  nm). The laser was focused to produce a spot diameter of 29  $\mu\text{m}$ , using a repetition rate of 8 Hz with an energy density of 4 J/cm<sup>2</sup>. Detailed operating conditions were illustrated in Li et al. (2012). NIST SRM 610 glass and Temora zircon ( $416.75 \pm 0.24$  Ma, Black et al., 2003) were used as external standards, and  $^{91}\text{Zr}$  was selected as internal standard. The raw ICP-MS data were exported in CSV format and processed using the ICPMSDataCal 10.1 software (Lin et al., 2016). Concordia diagrams and weighted mean calculations were made using Isoplot/Ex\_ver3 (Ludwig, 2003). Data errors of single spot were 1 $\sigma$  and those of weighted mean  $^{206}\text{Pb}/^{238}\text{U}$  ages were 2 $\sigma$ . To monitor the accuracy of the LA-ICP-MS U–Pb measurements, the Plešovice zircon was analyzed as the unknown sample. Twelve analyses yielded a weighted average  $^{206}\text{Pb}/^{238}\text{U}$  age of  $339.4 \pm 2.2$  Ma (2 $\sigma$ , MSWD = 2.6), consistent with the recommended age of  $337.13 \pm 0.37$  Ma (Sláma et al., 2008).

## 3. Zircon Lu–Hf isotopes

Lu–Hf isotopic analyses of zircon were carried out using a Neptune MC-ICP-MS equipped with a RESolution M-50 laser ablation system. A 45- $\mu\text{m}$  beam at 8-Hz repetition rate was applied during spot analyses. Analytical spots lie in the equivalent sites where zircon U–Pb dating was performed. Penglai zircon was used as the reference standard, with a recommended  $^{176}\text{Hf}/^{177}\text{Hf}$  ratio of  $0.282906 \pm 0.000010$  (2SD) (Li et al., 2010). Instrumental conditions and data acquisition were comprehensively described by Wu et al. (2006).

## 4. Whole-rock major and trace elements

Major elements were analyzed using a Rigaku RIX 2000 X-ray fluorescence spectrometer (XRF) on fused glass beads. Calibration lines used in quantitative analyses were produced by bivariate regression of 36 standard materials overlapping a wide range of silicate

compositions (Li et al., 2005). Analytical uncertainties were mostly between 1% and 5%. Whole-rock volatiles, including F, Cl and B, were determined by ion activity meter, XRF spectrometer and direct reading spectrometry, and the corresponding detection limits for F, Cl and B analyses were 0.02 wt.%, 20 ppm and 1.6 ppm, respectively. The  $\text{Fe}^{2+}$  analyses were conducted using dichromate titration.

Trace elements were analyzed using a Perkin-Elmer Sciex ELAN 6000 ICP-MS, using analytical procedures described by Li (1997). About 50 mg of powder for each sample was dissolved in high-pressure Teflon bombs using a  $\text{HF}+\text{HNO}_3$  mixture. Rh was used as internal standard to monitor the signal shift during counting, and the USGS rock standards GSR-1, GSR-2, GSR-3, AGV-2, BHVO-2 and SARM-4 were chosen for calibrating element concentrations of analyzed samples. Analytical uncertainties were generally better than 5%.

## 5. Whole-rock Sr and Nd isotopes

Sr and Nd isotopic analyses were measured using a Micromass IsoProbe multi-collector ICP-MS. Details of analytical procedures were described by Li et al. (2004) and Wei et al. (2002). Sr and REE were separated using cation columns, and Nd fractions were further separated using HDEHP-coated Kef columns. In order to correct mass fractionation,  $^{87}\text{Sr}/^{86}\text{Sr}$  ratios were normalized to  $^{87}\text{Sr}/^{86}\text{Sr} = 0.1194$ , and  $^{143}\text{Nd}/^{144}\text{Nd}$  ratios were normalized to  $^{143}\text{Nd}/^{144}\text{Nd} = 0.7219$ , respectively. The reported  $^{87}\text{Sr}/^{86}\text{Sr}$  and  $^{143}\text{Nd}/^{144}\text{Nd}$  ratios were adjusted, respectively, to the NBS SRM-987 standard  $^{87}\text{Sr}/^{86}\text{Sr} = 0.71025$  and the Shin Etsu JNdi-1 standard  $^{143}\text{Nd}/^{144}\text{Nd} = 0.512115$ .

## 6. Electron microprobe analysis

Mineral chemistry analyses were obtained from polished thin sections for biotite and feldspar using a JEOL JXA-8100 electron microprobe. The conditions for element determinations include 5- $\mu\text{m}$  beam size, 15-kV accelerating potential voltage, and 20-nA probe current. The accuracy of the reported values for the analyses was 1–10% depending on the abundance of the element.

## REFERENCES CITED

- Amelin, Y., Lee, D.C., Halliday, A.N., and Pidgeon, R.T., 1999, Nature of the Earth's earliest crust from hafnium isotopes in single detrital zircons: *Nature*, v. 399, p. 252–255, <https://doi.org/10.1038/20426>.
- Ballard, J.R., Palin, M.J., and Campbell, I.H., 2002, Relative oxidation states of magmas inferred from Ce(IV)/Ce(III) in zircon: application to porphyry copper deposits of northern Chile: *Contributions to Mineralogy and Petrology*, v. 144, p. 347–364, <https://doi.org/10.1007/s00410-002-0402-5>.
- Black, L.P., Kamo, S.L., Allen, C.M., Aleinikoff, J.N., Davis, D.W., Korsch, R.J., and Foudoulis, C., 2003, TEMORA 1: a new zircon standard for Phanerozoic U–Pb geochronology: *Chemical Geology*, v. 200, p. 155–170, [https://doi.org/10.1016/S0009-2541\(03\)00165-7](https://doi.org/10.1016/S0009-2541(03)00165-7).

- Blichert-Toft, J., and Albarède, F., 1997, The Lu–Hf isotope geochemistry of chondrites and the evolution of the mantle-crust system: *Earth and Planetary Science Letters*, v. 148, p. 243–258, [https://doi.org/10.1016/S0012-821X\(97\)00040-X](https://doi.org/10.1016/S0012-821X(97)00040-X).
- Ferry, J.M., and Watson, E.B., 2007, New thermodynamic models and revised calibrations for the Ti-in-zircon and Zr-in-rutile thermometers: *Contributions to Mineralogy and Petrology*, v. 154, p. 429–437, <https://doi.org/10.1007/s00410-007-0201-0>.
- Griffin, W.L., Pearson, N.J., Belousova, E., Jackson, S.E., Van Acherterbergh, E., O'Reilly, S.Y., and Shee, S.R., 2000, The Hf isotope composition of cratonic mantle: LAM-MC-ICPMS analysis of zircon megacrysts in kimberlites: *Geochimica et Cosmochimica Acta*, v. 64, p. 133–147, [https://doi.org/10.1016/S0016-7037\(99\)00343-9](https://doi.org/10.1016/S0016-7037(99)00343-9).
- Jacobsen, S.B., and Wasserburg, G.J., 1980, Sm–Nd isotopic evolution of chondrites: *Earth and Planetary Science Letters*, v. 50, p. 139–155, [https://doi.org/10.1016/0012-821X\(80\)90125-9](https://doi.org/10.1016/0012-821X(80)90125-9).
- Li, C.Y., Zhang, H., Wang, F.Y., Liu, J.Q., Sun, Y.L., Hao, X.L., Li, Y.L., and Sun, W.D., 2012, The formation of the Dabaoshan porphyry molybdenum deposit induced by slab rollback: *Lithos*, v. 150, p. 101–110, <https://doi.org/10.1016/j.lithos.2012.04.001>.
- Li, X.H., 1997, Geochemistry of the Longsheng Ophiolite from the southern margin of Yangtze Craton, SE China: *Geochemical Journal*, v. 31, p. 323–337, <https://doi.org/10.2343/geochemj.31.323>.
- Li, X.H., Liu, D.Y., Sun, M., Li, W.X., Liang, X.R., and Liu, Y., 2004, Precise Sm–Nd and U–Pb isotopic dating of the supergiant Shizhuyuan polymetallic deposit and its host granite, Southeast China: *Geological Magazine*, v. 141, p. 225–231, <https://doi.org/10.1017/S0016756803008823>.
- Li, X.H., Long, W.G., Li, Q.L., Liu, Y., Zheng, Y.F., Yang, Y.H., Chamberlain, K.R., Wan, D.F., Guo, C.H., Wang, X.C., and Tao, H., 2010, Penglai zircon megacrysts: a potential new working reference material for microbeam determination of Hf–O isotopes and U–Pb age: *Geostandards and Geoanalytical Research*, v. 34, p. 117–134, <https://doi.org/10.1111/j.1751-908X.2010.00036.x>.
- Li, X.H., Qi, C.S., Liu, Y., Liang, X.R., Tu, X.L., Xie, L.W., and Yang, Y.H., 2005, Petrogenesis of the Neoproterozoic bimodal volcanic rocks along the western margin of the Yangtze Block: New constraints from Hf isotopes and Fe/Mn ratios: *Chinese Science Bulletin*, v. 50, p. 2481–2486, <https://doi.org/10.1360/982005-287>.
- Li, X.H., Tang, G.Q., Gong, B., Yang, Y.H., Hou, K.J., Hu, Z.C., Li, Q.L., Liu, Y., and Li, W.X., 2013, Qinghu zircon: A working reference for microbeam analysis of U–Pb age and Hf and O isotopes: *Chinese Science Bulletin*, v. 58, p. 4647–4654, <https://doi.org/10.1007/s11434-013-5932-x>.
- Lin, J., Liu, Y.S., Yang, Y.H., and Hu, Z.C., 2016, Calibration and correction of LA-ICP-MS and LA-MC-ICP-MS analyses for element contents and isotopic ratios: *Solid Earth Sciences*, v. 1, p. 5–27, <https://doi.org/10.1016/j.sesci.2016.04.002>.
- Lin, W.W., and Peng, L.J., 1994, The estimation of Fe<sup>3+</sup> and Fe<sup>2+</sup> contents in amphibole and biotite from EPMA data [in Chinese with English abstract]: *Journal of Changchun University of Earth Sciences*, v. 24, p. 155–162.
- Ludwig, K.R., 2003, User's manual for Isoplot/Ex version 3.00: A geochronology toolkit for microsoft excel, No. 4: Berkeley Geochronological Center, Special Publication.

- Lugmair, G.W., and Marti, K., 1978, Lunar initial  $^{143}\text{Nd}/^{144}\text{Nd}$ : differential evolution of the lunar crust and mantle: *Earth and Planetary Science Letters*, v. 39, p. 349–357, [https://doi.org/10.1016/0012-821X\(78\)90021-3](https://doi.org/10.1016/0012-821X(78)90021-3).
- Sláma, J., Košler, J., Condon, D.J., Crowley, J.L., Gerdes, A., Hanchar, J.M., Horstwood, M.S.A., Morris, G.A., Nasdala, L., Norberg, N., Schaltegger, U., Schoene, B., Tubrett, M.N., and Whitehouse, M.J., 2008, Plešovice zircon—a new natural reference material for U–Pb and Hf isotopic microanalysis: *Chemical Geology*, v. 249, p. 1–35, <https://doi.org/10.1016/j.chemgeo.2007.11.005>.
- Söderlund, U., Patchett, P.J., Vervoort, J.D., and Isachsen, C.E., 2004, The  $^{176}\text{Lu}$  decay constant determined by Lu–Hf and U–Pb isotope systematics of Precambrian mafic intrusions: *Earth and Planetary Science Letters*, v. 219, p. 311–324, [https://doi.org/10.1016/S0012-821X\(04\)00012-3](https://doi.org/10.1016/S0012-821X(04)00012-3).
- Sun, S.S., and McDonough, W.F., 1989, Chemical and isotopic systematics of oceanic basalt: implication for mantle composition and processes, *in* Saunders, A.D., and Norry, M.J., eds., *Magmatism in the Ocean Basins*: Geological Society, London, Special Publications, v. 42, p. 313–345, <https://doi.org/10.1144/GSL.SP.1989.042.01.19>.
- Tindle, A.G., and Webb, P.C., 1990, Estimation of lithium contents in trioctahedral micas using microprobe data: application to micas from granitic rocks: *European Journal of Mineralogy*, v. 2, p. 595–610, <https://doi.org/10.1127/ejm/2/5/0595>.
- Wei, G.J., Liang, X.R., Li, X.H., and Liu, Y., 2002, Precise measurement of Sr isotopic compositions of liquid and solid base using (LA) MCICP-MS [in Chinese with English abstract]: *Geochimica*, v. 31, p. 295–305.
- Wu, F.Y., Yang, Y.H., Xie, L.W., Yang, J.H., and Xu, P., 2006, Hf isotopic compositions of the standard zircons and baddeleyites used in U–Pb geochronology: *Chemical Geology*, v. 234, p. 105–126, <https://doi.org/10.1016/j.chemgeo.2006.05.003>.





