Analytical methods

Zircon U-Pb dating and trace element analyses

Zircon U-Pb dating was conducted using LA-ICP-MS at the Mineral and Fluid Inclusion Microanalysis Lab, Institute of Geology, Chinese Academy of Geological Sciences, Beijing, China. The NWR 193^{UC} laser ablation system (Elemental Scientific Lasers, USA) was equipped with Coherent Excistar 200 excimer laser and a Two Volume 2 ablation cell. The laser ablation system was coupled to an Agilent 7900 ICP-MS (Agilent, USA). The detailed analytical methods have been described by [88]. Pre-ablation was conducted for each spot analysis using 5 laser shots (~0.3 μm in depth) to remove potential surface contamination. The analysis was performed using 30 μm diameter spot at 5 Hz and a fluence of 2 J/cm^2. Zircon 91500 and GJ-1 was used as primary and secondary reference materials respectively. Multiple groups of 10 to 12 sample unknowns were bracketed by triplets of primary and secondary zircon standards. Typically，35–40 seconds of the sample signals were acquired after 20 seconds gas background measurement. The measured ages of the reference materials in the batch are as follows: 91500 (1061.8 ± 3.9 Ma, 2σ), GJ-1 (604.4 ± 2.8 Ma, 2σ), which are well within 1% of the accepted ages [89]. NIST610 and ^{91}Zr were used to calibrate the trace element concentrations as external reference material and internal standard respectively. Iolite software package was used for data reduction [90].

In-situ zircon Lu-Hf isotopes

In-situ Lu-Hf analyses were carried out by a multiple collector-inductively coupled plasma-mass spectrometer (MC-ICP-MS, Neptune Plus, Thermo Fisher Scientific, Germany) in combination with a femtosecond (λ = 343 nm) laser ablation system (J-200, Applied Spectra, USA) at the National Research Center for Geoanalysis, Chinese Academy of Geological Sciences, Beijing, China. The detailed analytical procedures were described by [91]. Zircons were ablated for 31 s at a repetition rate of 8 Hz at 1.5 J/cm^2, and ablation pits were 20 × 40 μm in diameter. The isobaric interferences from ^{176}Yb and ^{176}Lu on ^{176}Hf were corrected using the reduction proposal recommended in [92]. Zircon Plesovice was used as the standard for data quality assessment, with measured values of ^{176}Hf/^{177}Hf = 0.282476 ± 0.000020 (n = 33, 2σ), which were indistinguishable from the recommended value of 0.282482 ± 0.000013 (2σ) [93].

Whole rock major and trace elements

Major element compositions of whole rocks were analyzed by X-ray fluorescence (Primus II, Rigaku, Japan). The detailed sample-digesting procedure was as follows: (1) Sample powder (200 mesh) were placed in an oven at 105 °C for drying of 12 hours; (2) ~1.0g dried sample was accurately weighted and placed in the ceramic crucible and then heated in a muffle furnace at 1000 °C for 2 hours. After cooling to 400 °C, this sample was placed in the drying vessel and weighted again in order to calculate the loss on ignition (LOI). (3) 0.6 g sample powder was mixed with 6.0 g cosolvent ($Li_2B_4O_7$: $LiBO_2$: LiF = 9 : 2 : 1) and 0.3 g oxidant (NH_4NO_3) in a Pt crucible, which was placed in the furnace at 1150 °C for 14 minutes. Then, this melting sample was quenched with air for 1 minute to produce flat discs on the fire brick for the XRF analyses.

Trace element analyses were conducted on Agilent 7700e ICP-MS. The detailed sample-digesting procedure was as follows: (1) Sample powder (200 mesh) were placed in an oven at 105 °C for drying of 12 hours; (2) 50 mg sample powder was accurately weighed and placed in

a Teflon bomb; (3) 1 ml HNO_3 and 1 ml HF were slowly added into the Teflon bomb; (4) Teflon bomb was putted in a stainless steel pressure jacket and heated to 190 °C in an oven for > 24 hours; (5) After cooling, the Teflon bomb was opened and placed on a hotplate at 140 °C and evaporated to incipient dryness, and then 1 ml HNO_3 was added and evaporated to dryness again; (6) 1 ml HNO_3, 1 ml MQ water and 1 ml internal standard solution of 1ppm In were added, and the Teflon bomb was resealed and placed in the oven at 190 °C for > 12 hours; (7) The final solution was transferred to a polyethylene bottle and diluted to 100 g by the addition of 2% HNO_3. All analyses were performed at the Wuhan SampleSolution Analytical Technology Co., Ltd., Wuhan, China.

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