Supporting Information

Detailed descriptions for Analytical Methods

Chemical and isotopic determinations were carried out via several different analysis methods in different independent laboratories to identify the utility of SA02 as a zircon reference material (Table 1). Trace element analysis was achieved using LA-ICP-MS. U-Pb dataset were produced by (CA)-ID-TIMS, SIMS and LA-ICP-MS. Laser fluorination and SIMS were used for measuring O isotopic compositions. As for Hf isotope, solution and laser ablation MC-ICP-MS were adopted for the ratio determinations. Full details of the analytical procedures have previously been reported [1-12], and analytical protocols are given here in brief.

Table 1. Summary of the methods employed on SA02 zircon crystal.

Sample	Trace element	U-Pb dating			Hf isotope		O isotope	
		(CA)-ID-TIMS	SIMS	LA-ICP-MS	Solution MC-ICP-MS	LA MC-ICP-MS	SIMS	Laser fluorination
SA02	IGGCAS	BGS TJCGS	IGGCAS	NWU CUG(WuHan) IGGCAS	IGGCAS	NWU IGGCAS	IGGCAS	USTC IGGCAS

BGS: British Geological Survey, U.K.
TJCGS: The Tianjin Centre, China Geological Survey (China)
IGGCAS: The Institute of Geology and Geophysics, Chinese Academy of Sciences (China)
NWU: The Northwest University (China)
USTC: The University of Science and Technology of China (China)
CUG (WuHan): The China University of Geosciences, Wuhan (China)

1 Trace Element determinations

Trace element analysis of the SA02 zircon were carried out using an Agilent 7500a quadrupole ICP-MS coupled with a Coherent Geolas HD 193 nm excimer laser ablation system at IGGCAS (Table 2). Helium gas was utilized as the carrier gas and mixed with argon gas downstream from the ablation cell. A repetition rate of 5 Hz, a spot size of 44 μm and a fluence of 5 J/cm^2 were adopted for the laser in the process of the measurement. Each spot analysis consists of approximate 20 s of background and 60 s of ablation. ARM-1 glass was used as the standard for the calibration of relative element sensitivities to achieve quantitative results of trace element [12]. The Glitter software was used for the data reduction [13]. More details for the analytical procedures are provided by Xie et al.[4].

Table 2. Typical solution/LA-ICP-MS instrument parameters for U-Pb dating, trace element and Hf isotopic compositions of SA02 zircon

MC-ICP-MS cup configuration									
Cup	**L4**	**L3**	**L2**	**L1**	**C**	**H1**	**H2**	**H3**	**H4**
Hf	^{172}Yb	^{173}Yb	^{175}Lu	^{176}Hf	^{177}Hf	^{178}Hf	^{179}Hf	^{180}Hf	^{182}W
Instrumentations									
Mass spectrometry			**Thermo Fisher Neptune Plus (MC-ICP-MS)**				**Agilent 7500a (ICP-Q-MS)**		
RF forward power (W)			~1200				~1400		
Interface cones			Nickel Standard Sampler cones and "H" Skimmer cones				Nickel cones		
Integration times			0.131s for laser Hf isotope; 4.191s for solution Hf isotope				6ms for Ti, Hf and REE; 10ms for ^{232}Th, ^{238}U; 15ms for ^{204}Pb, ^{206}Pb, ^{208}Pb; 30ms for ^{207}Pb		
Background/baseline			0s				20s		
Carrier gas (L/min)			~ 0.95				~ 0.85		

Laser ablation system	Geolas Pro/HD
Laser system	Compex 102, ArF excimer UV 193nm
Fluence	~ 5 J/cm^2 for trace element, U-Pb dating and Hf isotope
Spot size	44 µm for trace element and U-Pb dating; 32 µm for Hf isotope
Ablation duration	60s for trace element and U-Th-Pb dating; 26s for Hf isotope
Sampling mode/Repetition rate	Static spot ablation; 5 Hz for trace element and U-Pb dating, 6 Hz for Hf isotope
Sample preparation	Conventional mineral separation, 1inch resin mount
Imaging	Transmissive light, reflected light and CL imaging,
Data processing	
Reference material information	Trace element: ARM-1 glass is used as reference material U-Pb dating :91500 is used as primary reference material, and SA 01 is used as secondary standard for validation Hf isotope: Mud Tank is used as the primary standard for validation; SA 01 is used for the monitor standard.
Data processing package used	For trace elements and U-Pb data processing, Glitter software was used for isotopic and elemental fractionation, instrumental mass bias calibration. For Hf isotope, an in-house Microsoft Excel macro written in VBA (Visual Basic for Applications) was used for mass fraction correction, interference correction and uncertainty propagation
Common Pb correction	No common-Pb correction applied to data.
Uncertainty Level	Ages are quoted at 2s absolute unless otherwise stated.

2 U-Pb geochronology

2.1 CA-ID-TIMS (BGS)

Two SA02 zircon shards were first annealed at 900 °C for 60 h in a muffle furnace. Subsequently, individual shards were loaded into Teflon™ microcapsules with 100 µl of a ca. 5:1 mixture of 29 mol l^{-1} HF and 30% HNO_3 in which crystals were chemically abraded at 210 °C for 12 h. After chemical abrasion, residual crystal fragments were rinsed in 6 mol l^{-1} HCl and 30% HNO_3 solutions.

Cleaned crystals were spiked with ET2535 tracer solution and dissolved at 220 °C for 60 h using 120 µl of 29 mol l^{-1} HF with a trace amount of 30% HNO_3. The solutions were then dried down and dissolved in 3M HCl at 180°C for ~12 hours to convert the samples to chloride form, after which U and Pb were purified from the dissolved sample by anion-exchange column chemistry. U–Pb isotope measurements were performed on a Thermo Electron Triton instrument equipped with an ion-counting SEM system, in single ion-counter (peak-hopping) mode for monoatomic Pb and multiple Faraday detector mode for U-oxide at BGS. Data reduction, age calculation and uncertainty propagation were performed using Tripoli and ET_Redux software [14, 15]. A magma Th/U ratio of 2.8 was used for ^{230}Th disequilibrium correction and a ^{238}U/^{235}U ratio of 137.818 ± 0.045 was adopted in data reduction [16].

2.2 ID-TIMS (TJCGS)

The ID-TIMS analysis for SA02 zircon were performed at the TJCGS. Several SA02 zircon shards were microscopically selected based on clarity and apparent absence of inclusions or fractures. Before the analysis, acids used in the experiments were completely purified three times, and a Milli-Q system offers ultrapure water during the measurement. The zircon shards were successively washed in 1 mol l^{-1} HCl, 1 mol l^{-1} HNO_3 and 1 mol l^{-1} HF solutions at 100 °C for 2h, respectively. Cleaned crystals were dissolved in concentrated HF at 185 °C for 72h. the digested sample solutions were divided into two aliquots, one aliquot for Pb isotopic ratio measurements (ca. 65%) and the other for U-Pb contents determinations (ca. 35%) added five drops (ca.38 mg) of a mixed ^{208}Pb-^{235}U spike. Two solution aliquots were weighed accurately and then evaporated to dryness. Lead and U were separated using AG1 × 8 anion exchange resin with 6 mol l^{-1} HCl for

Pb isotope and 7 mol l^{-1} HNO_3 for U isotope. U-Pb isotopic ratios were measured on a Thermo Fisher Triton TIMS instrument with H_3PO_4 and silica gel onto degassed Re single filaments. Total procedural blanks in the process of measurements were 10-27 pg for Pb and 1-3 pg for U, respectively. IsoplotR [17, 18] software was employed for the date reduction. Common Pb was monitored using ^{204}Pb, and corrections were made based on the blank Pb isotopic composition and initial Pb isotopic composition given by the model of Stacey and Kramers [19].

2.3 SIMS (IGGCAS)

Measurements of U-Pb ages were conducted using CAMECA IMS 1280HR SIMS at IGGCAS following the published method [5]. A O_2^- primary beam of ca. 10 nA accelerated at -13 kV and an ellipsoidal spot of *ca.* 20 μm × 30 μm was adopted for the SIMS. An energy window of 60 eV and a mass resolution of ca. 5400 (at 10% peak height) were used to measure Pb ion peaks with isobaric interferences removal. Secondary ion beam signals were collected with a single electron multiplier on ion-counting mode by peak jumping sequences. Each measurement involves seven cycles. Obtained Pb/U ratios were calibrated relative to the zircon reference material Plešovice ($^{206}Pb/^{238}U$ age = 337 Ma) using a sample $^{238}U/^{235}U$ ratio of 137.818 ± 0.045 [16, 20]. For the uncertainty of single analytical spots, a long-term uncertainty of 1.5% (1s RSD) for $^{206}Pb/^{238}U$ measurements of the Plešovice zircon reference material was propagated [5]. The common lead correction was achieved using non-radiogenic ^{204}Pb and the data were processed using IsoplotR [17, 18]. Uncertainties of data on individual analyses are reported at the 1s level. Moreover, the 'external reproducibility' of the SIMS U-Pb analysis was assessed on the in-house zircon reference material (Qinghu) analyzed as an unknown together with other unknown zircons, giving a mean $^{206}Pb/^{238}U$ age of 159.0 ± 3.0 Ma (2s, n = 7) consistent with the reported value (159.45 ± 0.16 Ma) [5].

2.4 LA-ICP-MS (NWU)

The LA-ICP-MS U-Pb dating for SA02 zircon at NWU was performed using an Agilent 7900 ICP-MS coupled with a RESOLution M-50 193 nm laser system equipped with a two-volume laser ablation cell, a Squid smoothing device and a computer-controlled high-precision X-Y stage. The characteristic of two-volume cell comprises the capability of avoiding cross contamination and reducing background flushing time, while the Squid smoothing device could give a smooth signal with laser pulse rates down to 1 Hz. Helium was used as carrier during laser ablation and it entered the cell body at its bottom to fill the big cell. Helium from both bottom and top through the funnel cell entrained the sample aerosol and argon was admixed downstream, in front of the squid signal smoothing device, into the ICP-MS. Stability and sensitivity of the ICP-MS was optimized in solution mode before connected to a laser ablation system. The plasma was kept lighted during removing the spray chamber and connecting the laser ablation system. Line-scan mode was utilized to tune the operating parameters of ICP-MS using NIST SRM 610 glass. The nebulizer gas flow rate and the ion optics volts were optimized to maximize the sensitivity and to make sure the $^{232}Th^{16}O^+/^{232}Th^+$ ratios below 0.2% and the ratios of $^{238}U/^{232}Th$ among 0.96-1.00. A repetition rate of 5 Hz, a spot size of 43 μm and a fluence of 6 J/cm^2 were adopted for the laser. All measurements for isotopes of ^{238}U, ^{232}Th, ^{208}Pb, ^{207}Pb, ^{206}Pb, ^{204}Pb, and ^{202}Hg were collected in peak-jumping mode. Mass 204 was measured to monitor the presence of common Pb in zircon grains and ^{202}Hg was measured in order to correct for the isobaric interference of ^{204}Hg on ^{204}Pb. Zircon standard material 91500 was used as an external standard to calibrate the zircon U-Pb ages. Data reduction was performed using ICPMSDataCal software, and the results were normalized

according to 91500 [7, 21-23]. Zircon reference material Plešovice was analyzed as an unknown sample to monitor the accuracy and reproducibility of the measurement, which yielded a mean $^{206}Pb/^{238}U$ age of 338 ± 5 Ma (2s, n = 7) consistent with the reported value [20].

2.5 LA-ICP-MS (CUG (Wuhan))

U-Pb age determinations of the SA02 zircon were carried out using Agilent 7500a ICP-MS coupled with GeoLas 2005 193 nm laser ablation system at the State Key Laboratory of Geological Processes and Mineral Resources, China University of Geosciences, Wuhan following proposed methods [7, 8, 21], and a brief description is offered here. A "wire" signal smoothing device is used during the measurements, by which smooth signals are achieved even at very low laser repetition rates down to 1 Hz [24]. Argon was used as the make-up gas and mixed with the carrier gas of helium via a T-connector before entering the ICP adding Nitrogen to decrease the detection limit and improve precision [8, 25]). The data process was performed by ICPMSDataCal [7, 21]. Zircon reference material 91500 was used as external standard for U-Pb dating. Uncertainty of preferred values for zircon reference material 91500 was propagated to the ultimate results of the samples [22]. Concordia diagrams and weighted mean calculations were made using IsoplotR [17, 18]. Zircon reference material GJ-1 was analyzed together with SA02 zircon as an unknown to assess the 'external uncertainties' of measurements by LA-ICP-MS , which gave a mean $^{206}Pb/^{238}U$ age of 601 ± 8 Ma (2s, n = 13) consistent with the published value [26].

2.6 LA-ICP-MS (IGGCAS)

Analysis of U-Pb age was conducted by LA-ICP-MS at IGGCAS using the same system as for trace element determinations of SA02 zircon and identical instrument parameters reported by Xie et al.[4] (Table 2). Zircon reference material 91500 was used as the primary reference material for the correction of depth-dependent elemental and isotopic fractionation, mass discrimination and drift [22]. Software program ICPMSDataCal 9.0 was used for the data process [7]. The accuracy and reproducibility of the analyses were assessed by measurements of zircon reference material SA01, which gave a mean $^{206}Pb/^{238}U$ age of 535 ± 7 Ma (2s, n = 9) consistent with the reported value [27]. The age calculations and plotting of Concordia diagrams were performed using IsoplotR [17, 18].

3 Oxygen isotope determination

3.1 Laser fluorination (USTC and IGGCAS)

Oxygen isotope analysis of SA02 zircon using laser fluorination method were carried out in two laboratories, USTC and IGGCAS with the use of a Finnegan Delta XP mass spectrometer and a Thermo Scientific Fisher M252 mass spectrometer, respectively [28, 29]. O_2 was extracted utilizing a 25 W CO_2 laser (λ = 10.6 mm) and BrF_5 reagent for the $^{18}O/^{16}O$ ratios measurement normalized to VSMOW (Vienna Standard Mean Ocean Water) and expressed on the $\delta^{18}O$-scale [1, 30]. The 'external reference materials' of 91500 zircon ($\delta^{18}O$ = 9.86 ‰) and the 04BXL07 garnet ($\delta^{18}O$ = 3.70 ‰) were used for the data correction, respectively [1, 31].

3.2 SIMS (IGGCAS)

Determinations of oxygen isotopes were conducted using CAMECA IMS 1280 SIMS at IGGCAS. The analytical procedure was reported by Li et al.[6]. A Cs^+ primary beam of ca. 1.5 nA and a diameter of ca. 10mm were adopted for the SIMS. A normal electron gun was used to compensate the charge effect generated by bombarding the area. Two isotopes, ^{16}O and ^{18}O, were measured simultaneously. Zircon reference material Penglai ($\delta^{18}O$ = 5.31 ‰) was used as the primary reference material for data calibration using conventional standard-sample bracketing. Other zircon reference material Qinghu was measured as a quality control reference material, giving a mean of 5.32 ± 0.39‰ (2s, n = 14) consistent with the reported value [10].

4 Hf isotope determination

4.1 Solution MC-ICP-MS (IGGCAS)

The solution analysis of Hf isotope for SA02 zircon presented here were carried out at the IGGCAS. Full details of the dissolution and sequential extraction of Hf has previously been reported by Yang et al.[9]. A brief introduction is offered here. Fifteen zircon shards were dissolved in concentrated HF-HNO_3 at 220 °C for 3 days, followed by evaporated to dryness and re-dissolved in 3 mol l^{-1} HCl. A cation-exchange resin column was used to separate and purify Hf before analysis. Obtained samples were analyzed on a Thermo Scientific Fisher Neptune plus MC-ICP-MS. Instrumental mass bias was corrected using a $^{179}Hf/^{177}Hf$ ratio of 0.7325 by the exponential law. Measured ^{173}Yb and ^{175}Lu values were used to correct the possible isobaric interferences of ^{176}Yb and ^{176}Lu on ^{176}Hf, applying $^{176}Lu/^{175}Lu$ = 0.02655 and $^{176}Yb/^{173}Yb$ = 0.79631 and assuming the Yb and Lu mass discrimination is the same as that of Hf [32]. The accuracy of analysis is demonstrated by repeat analyses of Alfa Hf solution (JMC14374), which provided a mean $^{176}Hf/^{177}Hf$ value of 0.282198 ± 0.000013 (2s, n = 23) identical to the reported value within uncertainties [3, 9].

4.2 LA MC-ICP-MS (NWU)

The Lu–Hf isotopic compositions of SA02 zircon were analyzed by using a Nu Plasma II MC-ICP-MS connected to a RESOLution M-50 193 nm laser system at NWU. Helium acted as a carrier gas mixed with argon downstream. A spot size of 44 μm, a repetition rate of 6 Hz and an energy density of 6 J/cm^2 were used for the laser ablation system. Ion signals of ^{172}Yb, ^{173}Yb, ^{175}Lu, ^{176}(Hf +Yb +Lu), ^{177}Hf, ^{178}Hf, ^{179}Hf and ^{180}Hf were detected simultaneously. The detail information of these instruments, analysis strategy and data deduction can be found in published literature [33, 34]. Zircon reference material 91500 and Mud Tank were analyzed as an unknown sample to assess the quality of the data during the analysis. The obtained $^{176}Hf/^{177}Hf$ ratios of the 91500 zircon and Mud Tank zircon were 0.282293 ± 0.000035 (n=16, 2s) and 0.282510 ± 0.000033 (n=8, 2s), respectively, which are consistent with the reported value within analytical uncertainty [22, 35].

4.3 LA MC-ICP-MS (IGGCAS)

The Lu–Hf isotopic analyses for SA02 zircon were carried out by LA-MC-ICP-MS at IGGCAS using Thermo Scientific Fisher Neptune plus MC-ICP-MS attached with a Coherent Geolas Pro 193nm excimer laser ablation system. A laser spot size of 32μm or 44μm, a repetition rate of 6 Hz

and an energy density of *ca.* 5 J cm^{-2} were set for the laser ablation system (Table 2). The carrier gas consisted of helium, argon and nitrogen. The detailed analytical procedures were similar to those described previously [3]. An in-house Microsoft Excel macro written in VBA (Visual Basic for Applications) was used for data process including mass fraction correction, interference correction and uncertainty propagation. Instrumental mass bias for the $^{176}Yb/^{177}Hf$, $^{176}Lu/^{177}Hf$ and $^{176}Hf/^{177}Hf$ ratios were normalized to the natural abundance ratio of $^{179}Hf/^{177}Hf = 0.7325$ using the exponential law. The mean $^{173}Yb/^{172}Yb$ ratio of the individual spot was measured to calculate the fractionation coefficient (β_{Yb}) and the contribution of ^{176}Yb to ^{176}Hf by applying the natural abundance ratios of $^{176}Yb/^{172}Yb = 0.588673$ and $^{173}Yb/^{172}Yb = 0.73925$. The isobaric interference of ^{176}Lu on ^{176}Hf was corrected by measuring the intensity of the interference-free ^{175}Lu isotope with a recommended $^{176}Lu/^{175}Lu$ ratio of 0.02655 and assuming $\beta_{Lu} = \beta_{Yb}$ [3]. Accuracy and external reproducibility of the analyses were controlled by repeated analyses of reference zircon standards Mud Tank and SA01. The obtained $^{176}Hf/^{177}Hf$ value on the two reference materials are identical to the reported values within uncertainties, 0.282504 ± 0.000042 (2s, n=31) for Mud Tank zircon and 0.282285 ± 0.000047 (2s, n=15) for SA01 zircon [27, 35].

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