

# **Zircon record of supercontinent amalgamation in back-arc volcanic rocks**

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## **Contents of this file**

This supplementary materials file contains extended descriptions of analytical methods, extended information of the Ti-in-zircon temperature, Figure S1 to S10 and Table S1 to S8.

## **Supplementary analytical methods**

### ***Zircon separation and preparation***

The volcanic rock samples that are described in this paper were recovered by the TV grab method during a cruise of the R/V KEXUE HAO in 2014 and were collected at stations T9', C1 and R10-H2 (Fig. S1) in the SPOT. Before to separate zircons, the volcanic rock samples (Fig. S2) were first washed to remove adhering sediments. Then, they were cut into smaller pieces (1×1 cm), and any weathered rinds and adhering sediments were removed. The fresh fragments were cleaned in an ultrasonic bath for approximately 3 hours. The water in the bath was changed every 20 to 30 minutes. After these steps, the possible contamination of detrital zircons in the

25 adhering sediments can be removed. Finally, after drying in an oven at 60°C for 24 hours, all  
26 grains were pulverized to 200 mesh in an agate mill for zircon separation.

27 The zircons were separated by standard density and magnetic techniques and then manually  
28 selected under a binocular microscope. Representative zircon grains were mounted in epoxy  
29 resin and polished to expose their grain centres. To guide the selection of in situ analysis spots,  
30 cathodoluminescence (CL) images were obtained to reveal the external morphology and  
31 internal structure of zircons. The CL images were obtained using a HITACHI S3000-N  
32 scanning electron microscope at Nanjing Hong-chuang Geological Exploration Technology  
33 Service Company.

#### 34 ***Zircon $^{238}\text{U}$ - $^{230}\text{Th}$ dating***

35  $^{238}\text{U}$ - $^{230}\text{Th}$  disequilibrium dating was performed by SIMS using a CAMECA IMS 1270 at  
36 UCLA following the analytical protocol described by Schmitt et al. (2006). All zircon crystals  
37 were mounted in epoxy and polished to reveal a flat surface, which were coated with a  
38 conductive 20 to 30nm Au layer prior to analysis. Large zircon grains (mostly length > 100 $\mu\text{m}$ )  
39 in the samples were chosen for in situ analysis (using a 25 to 30 $\mu\text{m}$  spot size). The ion  
40 microprobe  $^{230}\text{Th}/^{232}\text{Th}$  and  $^{238}\text{U}/^{232}\text{Th}$  analyses with the CAMECA IMS 1270 routinely  
41 achieved a relative precision and accuracy of approximately 1–2% with a spot size of  
42 approximately 50  $\mu\text{m}$  and a depth resolution of <3  $\mu\text{m}$  in the single electron multiplier collector  
43 peak-jumping mode. The accuracy was monitored by interspersed analyses according to the  
44 AS3 and Qinghu zircon standards (Liu et al., 2011); the former yielded a unity secular  
45 equilibrium ratio of  $^{230}\text{Th}/^{238}\text{U} = 1.022 \pm 0.016$  (activities denoted in parentheses; mean squared  
46 weighted deviation (MSWD) = 0.5; n = 6; Table S4), and the latter yielded a unity secular

47 equilibrium ratio of  $^{230}\text{Th}/^{238}\text{U} = 1.098 \pm 0.015$  (MSWD = 2.2; n = 25; Table S4). The  
48 crystallization age was calculated by a correction scheme in Python code using the measured  
49 zircon  $^{238}\text{U}/^{232}\text{Th}$  ratio and the U/Th partition coefficient ratio between zircon and melt  
50 (Boehnke et al., 2016).

### 51 ***Zircon trace element analysis***

52 Zircon trace element abundances were acquired using the UCLA CAMECA IMS 1270 ion  
53 probe (SIMS). Secondary ions were generated by bombarding the sample surface with a mass-  
54 filtered  $^{16}\text{O}^-$  primary ion beam at a current of approximately 60 nA focused on a  $25 \times 30 \mu\text{m}$  oval  
55 spot. The secondary ion accelerating voltage was 10 kV, and secondary ions with an energy  
56 bandpass of 50 eV were analysed at a mass resolution ( $m/\Delta m$ ) of approximately 4500. The  
57 combined secondary magnet settling and dwell time per mass cycle was approximately 45 s,  
58 and 100 cycles were acquired per individual profile. These conditions resulted in depth intervals  
59 of approximately  $0.2 \mu\text{m}$  per cycle, with a total depth for an individual profile of approximately  
60  $20 \mu\text{m}$ . Sensitivity factors were calibrated from the analysis of the National Institute of Standard  
61 and Technology (NIST) standard glasses and the 91500 zircon standard (Yuan et al., 2007).  
62 More details about the zircon trace element analysis are described by Bell and Harrison (2013).

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

64 Measurements of the U-Pb isotope composition were conducted using a CAMECA IMS  
65 1280HR SIMS at the IGGCAS, Beijing. The instrument description and analytical procedures  
66 can be found in Li et al. (2009), and only a brief summary is given here. The primary  $\text{O}_2^-$  ion  
67 beam spot was approximately  $15 \times 10 \mu\text{m}$  in size. Positive secondary ions were extracted with a  
68 10kV potential. In the secondary ion beam optics, a 60eV energy window was used, together

69 with a mass resolution of approximately 5400 (at a 10% peak height), to separate  $\text{Pb}^+$  peaks  
70 from isobaric interferences. A single electron multiplier was used in the ion-counting mode to  
71 measure the secondary ion beam intensity by the peak-jumping mode. Analyses of the zircon  
72 standard Plesovice were interspersed with analyses of the unknown grains. Each measurement  
73 consisted of 7 cycles. Pb/U calibration was performed relative to the zircon standard Plesovice  
74 ( $^{206}\text{Pb}/^{238}\text{U}$  age = 337 Ma; Sláma et al., 2008); the U and Th concentrations were calibrated  
75 against the zircon standard 91500 (Th = 29 ppm, and U = 81 ppm; Wiedenbeck et al., 1995). A  
76 long-term uncertainty of 1.5% ( $1\sigma$  relative standard deviation (RSD)) for the  $^{206}\text{Pb}/^{238}\text{U}$   
77 measurements of the standard zircons was propagated to the unknowns (Li et al., 2010a),  
78 although the measured  $^{206}\text{Pb}/^{238}\text{U}$  error in a specific session was generally  $\leq 1\%$  ( $1\sigma$  RSD). The  
79 measured compositions were corrected for common Pb using nonradiogenic  $^{204}\text{Pb}$ . The  
80 corrections were sufficiently small to be insensitive to the choice of the common Pb  
81 composition; thus, an average of the present-day crustal composition (Stacey and Kramers,  
82 1975) was used for the common Pb assuming that this Pb was largely surface contamination  
83 introduced during sample preparation. Data reduction was carried out using the Isoplot/Ex v.  
84 2.49 program (Ludwig, 2001). The concordia U-Pb ages are quoted with 95% confidence  
85 intervals, except where noted otherwise. To monitor the external uncertainties of SIMS U-Pb  
86 zircon dating calibrated against the Plesovice standard, an in-house zircon standard Qinghu was  
87 also analysed as an unknown together with the other unknown zircons. Thirty-four  
88 measurements of the Qinghu zircon (Table S5) yielded a concordia age of  $159.1 \pm 1.5$  Ma, which  
89 was identical within the error margin to the recommended value of  $159.5 \pm 0.2$  Ma (Li et al.,  
90 2013).

91 ***Zircon O analysis***

92 The in situ zircon oxygen isotope compositions were analysed in the same grains that were  
93 previously dated using the same CAMECA IMS 1280 at the IGGCAS. Details of the analytical  
94 procedures are described by Tang et al. (2015). The mount was repolished to remove any  
95 oxygen implanted in the zircon surface during the U-Pb dating process. The Cs<sup>+</sup> primary ion  
96 beam was accelerated at 10kV at an intensity of approximately 2 nA. The spot size was  
97 approximately 20µm in diameter. The normal-incidence electron flood gun was used to  
98 compensate for sample charging during analysis with a homogeneous electron density across a  
99 100-µm oval area. Nuclear magnetic resonance (NMR) was applied to stabilize the magnetic  
100 field. The oxygen isotope compositions were measured using the multi-collection mode on two  
101 off-axis Faraday cups. The measured oxygen isotope ratios were reported in standard per mil  
102 notation relative to Vienna standard mean ocean water ( $V_{SMOW}$ ,  $^{18}O/^{16}O = 0.0020052$ ; Faghihi  
103 et al., 2015). The instrumental mass fraction (IMF) factor was corrected by replicate analyses  
104 on the zircon standard Penglai with a  $\delta^{18}O$  value of 5.3‰ (Li et al., 2010b). The internal  
105 precision of a single analysis was generally higher than 0.20‰ (2 $\sigma$  standard error) for the  
106  $^{18}O/^{16}O$  ratio. During the course of this study, the in-house zircon standard Qinghu was also  
107 analysed as an unknown together with the other unknowns. The measurements of the Qinghu  
108 zircon yielded a weighted mean value consistent within the error margin with the reported value  
109 of  $5.4 \pm 0.2\%$  (Li et al., 2013) (Table S6). All data for the in situ oxygen isotope analysis are  
110 listed in Tables S1 and S2.

111 ***Zircon Lu–Hf isotope measurements***

112 After SIMS zircon U-Pb dating and O isotope and trace element analyses, zircon in situ Hf

113 isotope analysis was carried out using LA-MC-ICP-MS at Nanjing University, Nanjing, China.  
114 The measurements were performed on polished, sectioned zircon grains mounted in epoxy resin,  
115 as guided by CL and transmitted light images and U-Pb age data, and the measurements  
116 involved ablating the shallow pits generated by the preceding SIMS analysis. These analyses  
117 were conducted with a beam diameter of 44  $\mu\text{m}$ , a repetition rate of 8 Hz, and a laser power of  
118 approximately 15 J/cm<sup>2</sup>. The aerosols ablated by the laser were transported to the mass  
119 spectrometer for isotopic determination with He as the carrier gas. All the Lu-Hf isotope results  
120 are reported with an error of 2 $\sigma$  of the mean. Zircons 91500 and Mud Tank were used as the  
121 reference standards during our routine analyses, yielding <sup>176</sup>Hf/<sup>177</sup>Hf ratios of  
122 0.282291±0.000014 (2SD, n=31; Table S7) and 0.282488±0.000009 (2SD, n=31; Table S7),  
123 respectively. These values are consistent with the recommended <sup>176</sup>Hf/<sup>177</sup>Hf ratios of  
124 0.282306±0.000010 for zircon 91500 (Woodhead et al., 2004) and 0.282507 ±0.000006 for the  
125 Mud Tank zircon (Woodhead and Hergt, 2005) within the analytical error margins.

### 126 *Ti-in-zircon temperature*

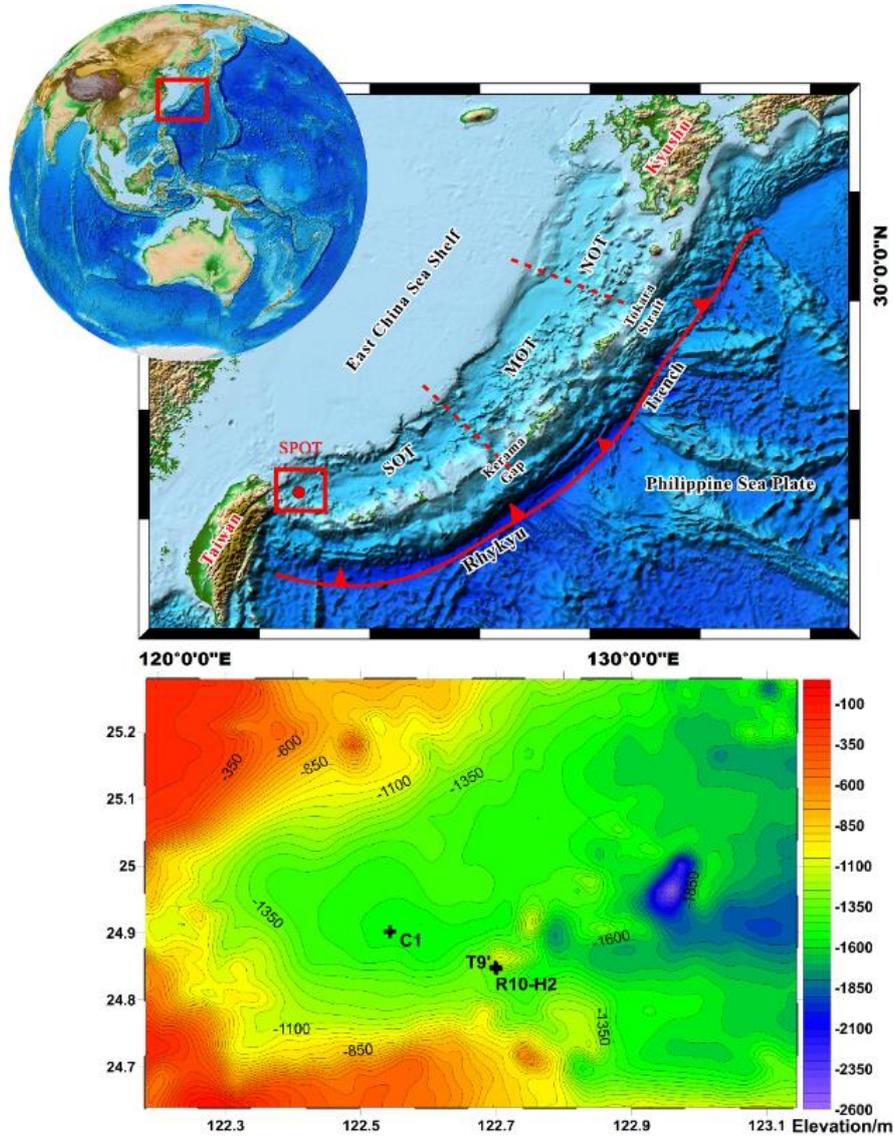
127 The temperatures used here were obtained using a Ti-in-zircon thermometer, following the  
128 method by Ferry and Watson (2007).

$$129 \quad \log \text{Ti}_{\text{Zircon}} = (5.711 \pm 0.0772) - (4800 \pm 86) / (T + 273.15) - \log \alpha_{\text{SiO}_2} + \log \alpha_{\text{TiO}_2}$$

130 The activities of SiO<sub>2</sub> and TiO<sub>2</sub> were assumed to be 1 because rutile has been observed in the  
131 samples (Li et al., 2019). The titanium values in the LCLZs ranged from 5.6 to 58.6 ppm in the  
132 R10-H2 rhyolite, from 3.9 to 110.7 ppm in the T9' rhyolite and from 5.1 to 48.0 ppm in the C1  
133 dacite, which yielded Ti-in-zircon temperatures of 693-924°C, 664–1008°C, and 685–900°C,  
134 respectively (Table S3).

135

136 **Supplementary Figures**



137

138 **Figure S1.** Geological map of the Okinawa Trough (OT), which is comprised of three segments:

139 Northern OT (NOT); Middle OT (MOT); Southern OT (SOT). The global inset in the upper

140 left corner shows the location of the OT in western Pacific. The red box at the southernmost

141 part of the OT (SPOT) is the research area in this study. The detailed e research area and

142 sampling locations are shown in the bathymetric map.

143



144

C1

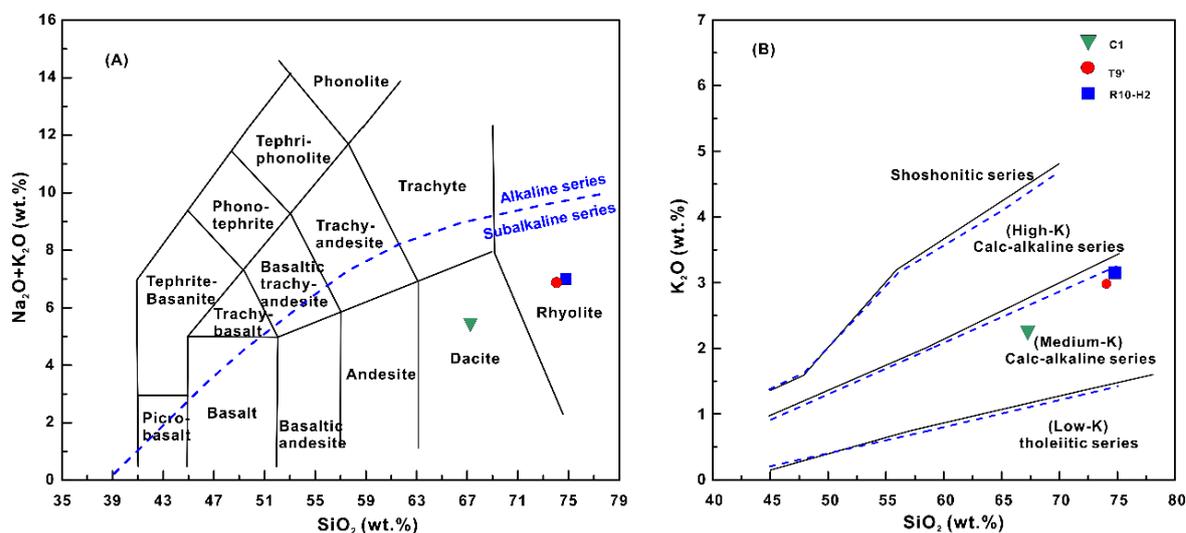
T9'

R10-H2

145 **Figure S2.** Hand specimen photographs of the studied samples.

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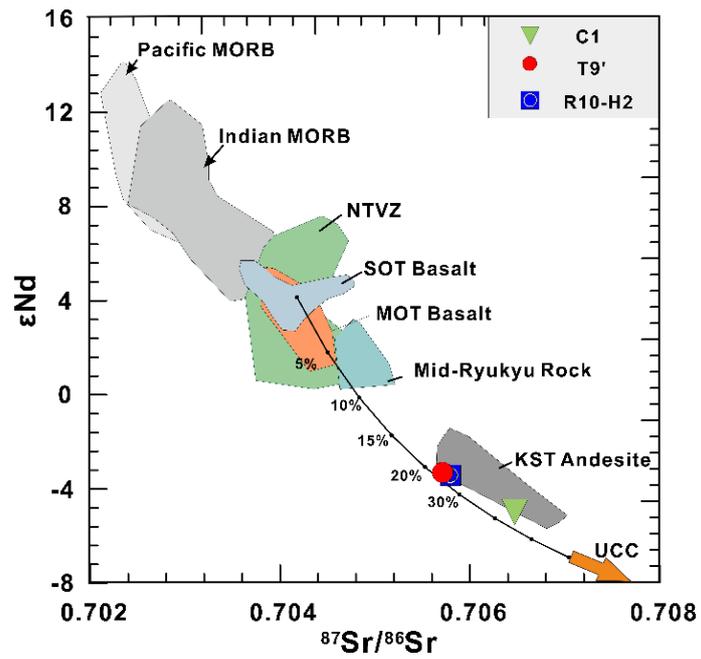
148

149 **Figure S3.** Classification diagrams for the studied rocks from the SPOT. (A) Total alkalis versus

150 silica diagram [(Na<sub>2</sub>O+K<sub>2</sub>O) vs. SiO<sub>2</sub>] of Bas et al. (1986). (B) K<sub>2</sub>O versus SiO<sub>2</sub>; the

151 boundaries are according to Roberts and Clemens (1993).

152

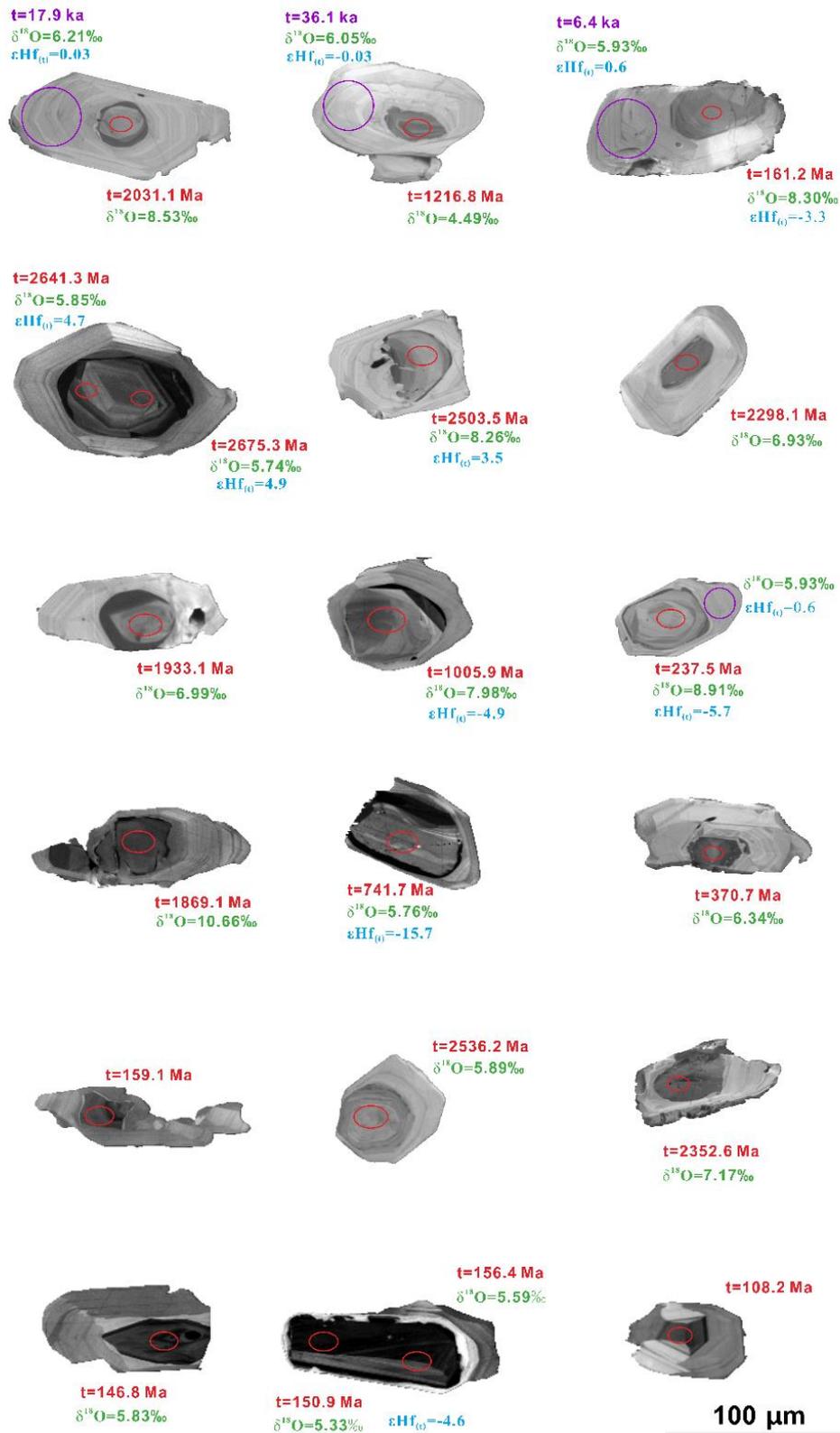


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154 **Figure S4.**  $^{87}\text{Sr}/^{86}\text{Sr}$  versus  $^{143}\text{Nd}/^{144}\text{Nd}$  diagram for the studied volcanic rocks; the fields  
 155 according to Chen et al. (2019). NTVZ = northern Taiwan Volcanic Zone. KST= Kueishantao  
 156 islet. MORB= mid-ocean ridge basalt. UCC= upper continental crust.

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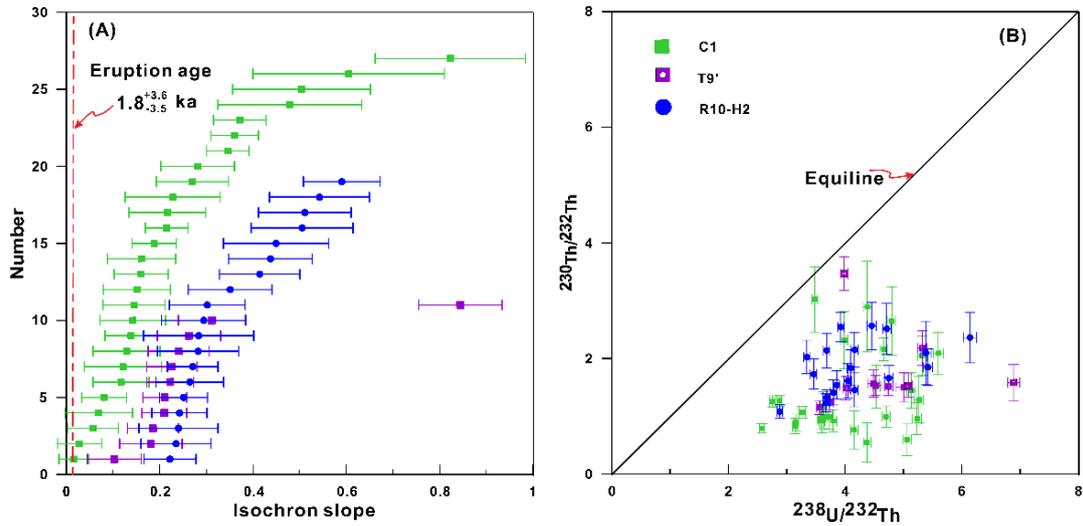


159

160 **Figure S5.** CL images of the dark-CL zircon cores (DCLZs) enveloped in the light-CL zircons

161 (LCLZs) with SIMS ages,  $\delta^{18}\text{O}$  isotope compositions and LA-MC-ICP-MS Hf isotope data.

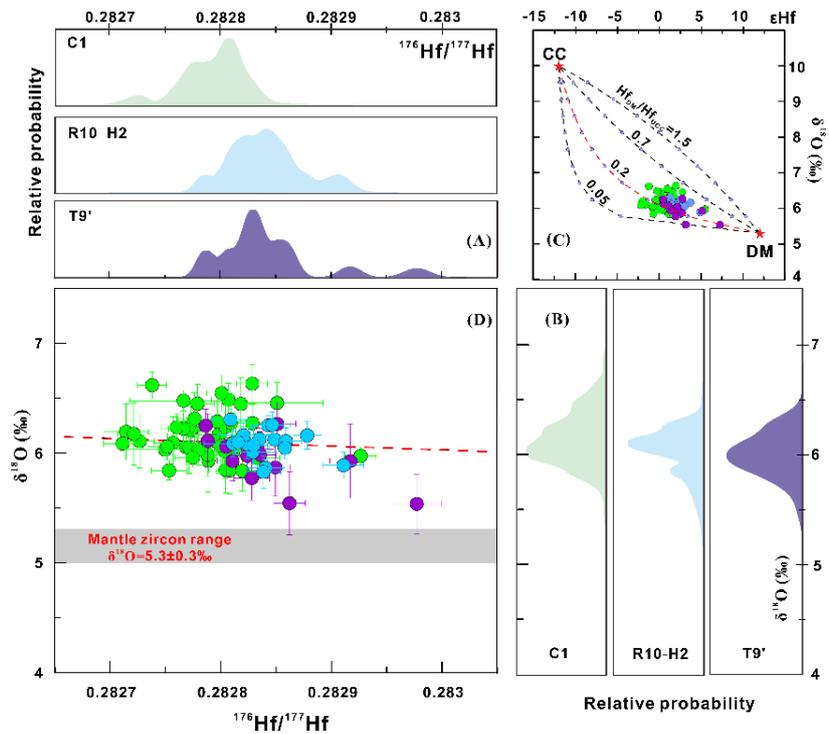
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163

164 **Figure S6.** (A) Rank order plots of the slopes of the  $^{238}\text{U}$ - $^{230}\text{Th}$  model (slope + 1 s output by  
 165 the code of Boehnke et al. (2016) showing an extensive range from approximately volcanic  
 166 eruption age to near the equiline. (B)  $^{230}\text{Th}/^{232}\text{Th}$  versus  $^{238}\text{U}/^{232}\text{Th}$  activity ratio diagram for the  
 167 SIMS LCLZ analyses of the dacite and rhyolite samples.

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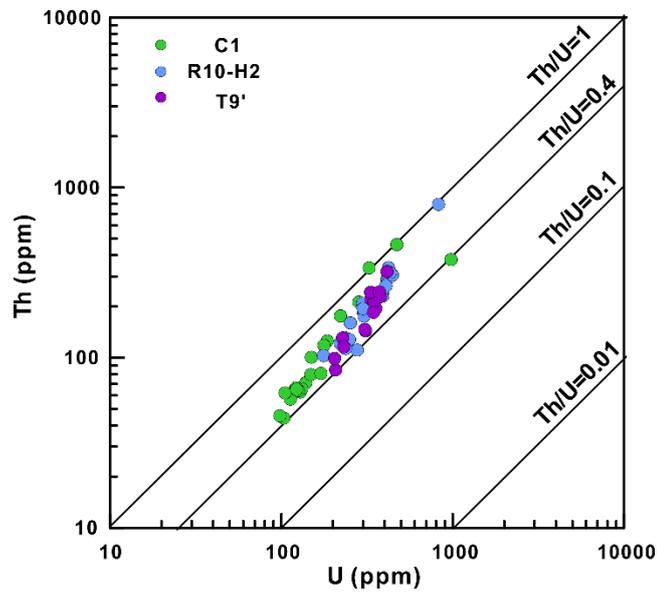


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170 **Figure S7.** Oxygen and hafnium isotope systematics of the LCLZs. A-B: The oxygen and

171 hafnium isotopic heterogeneities in the LCLZs are displayed as kernel density estimates. C-D:  
 172 Oxygen-hafnium isotope covariance-based models of the mixing between mantle and crustal  
 173 sources. The end member compositions of the zircons from the depleted mantle (DM;  $\epsilon_{\text{Hf}} = 12$ ,  
 174  $\delta^{18}\text{O} = 5.6\text{‰}$ ) and the continental crust (CC;  $\epsilon_{\text{Hf}} = -12$ ,  $\delta^{18}\text{O} = 10\text{‰}$ ) are according to Li et al.  
 175 (2009).

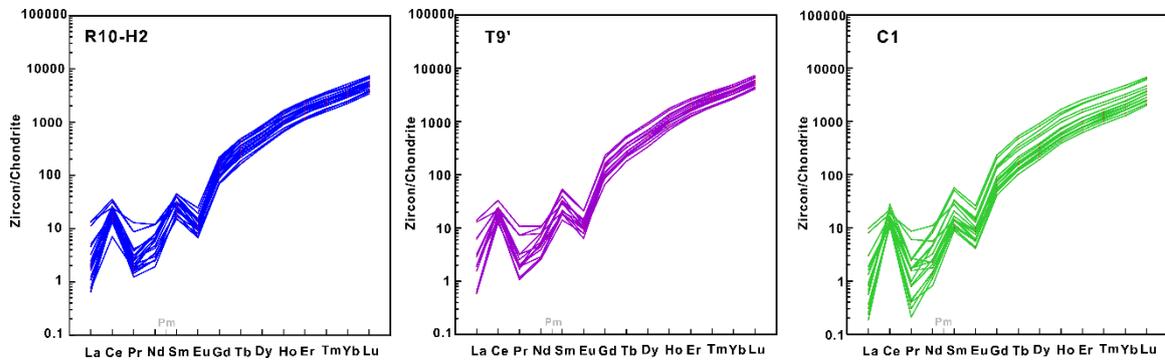
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177

178 **Figure S8.** Th-U plot of the LCLZs from the studied samples. The LCLZs in the back-arc  
 179 volcanic rock samples have high Th/U ratios (0.4-1.0).

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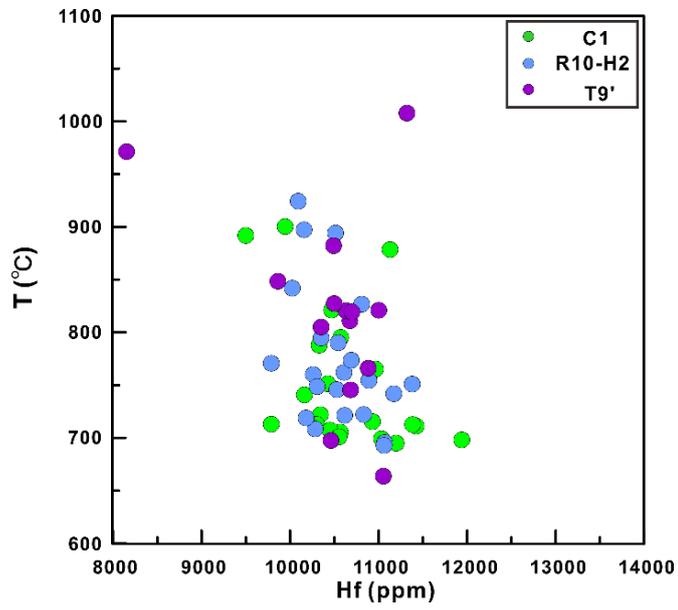


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182 **Figure S9.** Rare earth element (REE) concentrations in the LCLZs normalized to chondrite  
 183 (McDonough and Sun, 1995).

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187 **Figure S10.** Ti-in-zircon temperature versus Hf concentration in the LCLZs.

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192 **Supplementary tables**

193

**Table S1. SIMS zircon U-Th and O analyses and corresponding LA-MC-ICP-MS Hf isotope results for the LCLZs in the volcanic rocks.**

| <i>Sample</i>      | $(^{238}\text{U}/^{232}\text{Th})$ | <i>Is</i> | $(^{230}\text{Th}/^{232}\text{Th})$ | <i>Is</i> | <i>Th age</i> | <i>pos Is</i> | <i>neg Is</i> | <i>U</i> | $^{176}\text{Hf}/^{177}\text{Hf}$ | 2SE      | $\epsilon\text{Hf}$ | $\delta^{18}\text{O}$ | 2SE  |
|--------------------|------------------------------------|-----------|-------------------------------------|-----------|---------------|---------------|---------------|----------|-----------------------------------|----------|---------------------|-----------------------|------|
| R10-H2-2@1.ais     | 4.05                               | 0.06      | 1.61                                | 0.29      | 38.1          | 15.1          | -13.2         | 68       | 0.282829                          | 0.000016 | 2.02                | 6.01                  | 0.11 |
| R10-H2-2@2.ais     | 3.68                               | 0.05      | 2.14                                | 0.30      | 78.2          | 24.8          | -20.2         | 113      | 0.282849                          | 0.000014 | 2.71                | 6.12                  | 0.12 |
| R10-H2-3@3.ais     | 3.68                               | 0.06      | 1.32                                | 0.14      | 31.6          | 7.7           | -7.3          | 153      | 0.282859                          | 0.000014 | 3.07                | 6.11                  | 0.12 |
| R10-H2-4@4.ais     | 4.75                               | 0.07      | 1.66                                | 0.22      | 30.3          | 8.9           | -8.2          | 110      | 0.282818                          | 0.000015 | 1.62                | 5.87                  | 0.07 |
| R10-H2-5@5.ais     | 5.39                               | 0.09      | 2.09                                | 0.55      | 36.4          | 19.7          | -16.7         | 44       | 0.282849                          | 0.000014 | 2.74                | 5.89                  | 0.12 |
| R10-H2-6@6.ais     | 2.88                               | 0.05      | 1.08                                | 0.12      | 34.5          | 8.4           | -7.8          | 270      | 0.282822                          | 0.000014 | 1.77                | 6.01                  | 0.11 |
| R10-H2-8@7.ais     | 4.71                               | 0.07      | 2.51                                | 0.45      | 65.2          | 25.0          | -20.4         | 75       | 0.282784                          | 0.000013 | 0.41                | 6.05                  | 0.10 |
| R10-H2-10@8.ais    | 3.93                               | 0.06      | 2.55                                | 0.25      | 97.5          | 24.6          | -20.0         | 309      | -                                 | -        | -                   | 6.07                  | 0.17 |
| R10-H2-11@9.ais    | 3.85                               | 0.06      | 1.54                                | 0.25      | 39.3          | 13.5          | -12.0         | 172      | -                                 | -        | -                   | 6.08                  | 0.13 |
| R10-H2-13@11.ais   | 3.46                               | 0.05      | 1.73                                | 0.26      | 58.4          | 17.4          | -15.0         | 276      | 0.282821                          | 0.000018 | 1.72                | 6.09                  | 0.12 |
| R10-H2-14@12.ais   | 3.34                               | 0.05      | 2.03                                | 0.29      | 85.4          | 29.1          | -22.9         | 137      | 0.282812                          | 0.000023 | 1.41                | 6.10                  | 0.09 |
| R10-H2-15@13.ais   | 4.46                               | 0.08      | 2.56                                | 0.41      | 76.9          | 27.2          | -21.8         | 112      | 0.282878                          | 0.000016 | 3.75                | 6.11                  | 0.12 |
| R10-H2-15-2@14.ais | 6.14                               | 0.11      | 2.36                                | 0.44      | 36.2          | 14.1          | -12.5         | 104      | 0.282810                          | 0.000012 | 1.35                | 6.12                  | 0.12 |
| R10-H2-15-3@15.ais | 4.10                               | 0.06      | 1.84                                | 0.31      | 47.2          | 16.2          | -14.1         | 114      | 0.282821                          | 0.000014 | 1.74                | 6.13                  | 0.09 |
| R10-H2-16@16.ais   | 4.16                               | 0.06      | 1.46                                | 0.29      | 30.0          | 12.9          | -11.5         | 62       | 0.282821                          | 0.000026 | 1.72                | 6.16                  | 0.11 |
| R10-H2-17@17.ais   | 5.42                               | 0.08      | 1.85                                | 0.32      | 29.2          | 11.3          | -10.2         | 101      | 0.282841                          | 0.000012 | 2.45                | 6.16                  | 0.13 |
| R10-H2-18@18.ais   | 4.16                               | 0.06      | 2.15                                | 0.30      | 62.8          | 18.9          | -16.1         | 130      | 0.282826                          | 0.000015 | 1.90                | 6.16                  | 0.11 |
| R10-H2-19@19.ais   | 3.80                               | 0.06      | 1.41                                | 0.22      | 33.6          | 11.3          | -10.3         | 161      | 0.282839                          | 0.000014 | 2.39                | 6.18                  | 0.56 |
| R10-H2-21@21.ais   | 3.68                               | 0.05      | 1.24                                | 0.16      | 27.4          | 8.2           | -7.6          | 118      | 0.282807                          | 0.000013 | 1.25                | 6.23                  | 0.69 |
| C1-1@1.ais         | 5.60                               | 0.08      | 2.09                                | 0.36      | 34.4          | 12.2          | -11.0         | 46       | 0.282721                          | 0.000015 | -1.79               | 6.17                  | 0.28 |
| C1-2@2.ais         | 4.53                               | 0.07      | 1.51                                | 0.37      | 28.2          | 15.5          | -13.6         | 76       | 0.282780                          | 0.000016 | 0.28                | 6.03                  | 0.14 |
| C1-3@3.ais         | 3.63                               | 0.05      | 1.19                                | 0.23      | 26.6          | 12.1          | -10.9         | 137      | 0.282760                          | 0.000015 | -0.43               | 5.94                  | 0.13 |
| C1-5@5.ais         | 3.27                               | 0.05      | 1.07                                | 0.10      | 26.4          | 6.6           | -6.2          | 112      | 0.282767                          | 0.000019 | -0.16               | 6.17                  | 0.12 |

TableS1 (continued)

| <i>Sample</i>  | $(^{238}\text{U}/^{232}\text{Th})$ | <i>1s</i> | $(^{230}\text{Th}/^{232}\text{Th})$ | <i>1s</i> | <i>Th age</i> | <i>pos 1s</i> | <i>neg 1s</i> | <i>U</i> | $^{176}\text{Hf}/^{177}\text{Hf}$ | 2SE      | $\epsilon\text{Hf}$ | $\delta^{18}\text{O}$ | 2SE  |
|----------------|------------------------------------|-----------|-------------------------------------|-----------|---------------|---------------|---------------|----------|-----------------------------------|----------|---------------------|-----------------------|------|
| C1-6@6.ais     | 3.80                               | 0.06      | 0.92                                | 0.18      | 13.6          | 7.7           | -7.2          | 139      | 0.282711                          | 0.000017 | -2.15               | 6.09                  | 0.15 |
| C1-7@7.ais     | 3.99                               | 0.06      | 2.32                                | 0.50      | 76.6          | 38.7          | -28.5         | 205      | 0.282752                          | 0.000018 | -0.72               | 6.06                  | 0.12 |
| C1-9@9.ais     | 3.60                               | 0.05      | 0.92                                | 0.20      | 15.1          | 9.4           | -8.7          | 106      | 0.282741                          | 0.000014 | -1.10               | 6.03                  | 0.10 |
| C1-10@10.ais   | 2.88                               | 0.04      | 1.27                                | 0.10      | 46.3          | 7.9           | -7.4          | 291      | 0.282774                          | 0.000016 | 0.06                | 4.89                  | 0.99 |
| C1-11@11.ais   | 5.06                               | 0.08      | 0.60                                | 0.28      | 1.8           | 3.6           | -3.5          | 74       | 0.282775                          | 0.000016 | 0.10                | 5.96                  | 0.09 |
| C1-12@12.ais   | 4.71                               | 0.07      | 0.99                                | 0.19      | 9.2           | 5.9           | -5.6          | 350      | 0.282771                          | 0.000017 | -0.03               | 6.24                  | 0.09 |
| C1-13@13.ais   | 4.16                               | 0.06      | 0.76                                | 0.33      | 7.9           | 8.9           | -8.2          | 87       | 0.282782                          | 0.000013 | 0.35                | 6.23                  | 0.12 |
| C1-13-2@14.ais | 3.16                               | 0.05      | 0.89                                | 0.14      | 19.1          | 7.8           | -7.3          | 173      | 0.282807                          | 0.000014 | 1.25                | 6.03                  | 0.10 |
| C1-14@15.ais   | 3.58                               | 0.05      | 0.96                                | 0.19      | 17.1          | 8.9           | -8.2          | 84       | 0.282753                          | 0.000016 | -0.67               | 5.84                  | 0.09 |
| C1-19@19.ais   | 4.66                               | 0.07      | 2.16                                | 0.19      | 50.8          | 10.2          | -9.4          | 237      | 0.282807                          | 0.000015 | 1.23                | 6.49                  | 0.15 |
| C1-20@20.ais   | 3.73                               | 0.06      | 0.99                                | 0.22      | 16.7          | 9.4           | -8.6          | 129      | 0.282776                          | 0.000015 | 0.16                | 6.31                  | 0.17 |
| C1-22@21.ais   | 4.37                               | 0.06      | 0.55                                | 0.34      | 3.1           | 5.5           | -5.2          | 94       | 0.282801                          | 0.000013 | 1.02                | 6.55                  | 0.16 |
| C1-23@22.ais   | 2.75                               | 0.04      | 1.25                                | 0.10      | 48.9          | 9.1           | -8.4          | 186      | 0.282821                          | 0.000015 | 1.75                | 6.62                  | 0.12 |
| C1-25@23.ais   | 2.57                               | 0.04      | 0.79                                | 0.08      | 22.8          | 6.6           | -6.2          | 238      | 0.282766                          | 0.000014 | -0.21               | 6.22                  | 0.15 |
| C1-1-7@1.ais   | 4.80                               | 0.07      | 2.65                                | 0.60      | 71.2          | 38.4          | -28.4         | 52       | 0.282769                          | 0.000022 | -0.12               | 6.05                  | 0.17 |
| C1-1-10@2.ais  | 5.23                               | 0.08      | 0.96                                | 0.27      | 6.4           | 6.5           | -6.1          | 95       | 0.282789                          | 0.000014 | 0.59                | 5.93                  | 0.28 |
| C1-1-14@3.ais  | 3.14                               | 0.05      | 0.83                                | 0.13      | 16.3          | 7.3           | -6.9          | 182      | 0.282789                          | 0.000014 | 0.59                | 6.16                  | 0.35 |
| C1-2-8@1.ais   | 3.64                               | 0.06      | 0.99                                | 0.21      | 17.9          | 9.7           | -8.9          | 79       | 0.282773                          | 0.000013 | 0.03                | 6.21                  | 0.26 |
| C1-2-11@2.ais  | 5.32                               | 0.08      | 2.05                                | 0.34      | 36.1          | 12.7          | -11.4         | 103      | 0.282771                          | 0.000015 | -0.03               | 6.05                  | 0.24 |
| C1-2-9@3.ais   | 5.27                               | 0.08      | 1.29                                | 0.40      | 14.1          | 10.8          | -9.8          | 66       | 0.282788                          | 0.000013 | 0.56                | 5.98                  | 0.19 |
| C1-2-5@4.ais   | 5.14                               | 0.08      | 1.45                                | 0.31      | 19.2          | 9.9           | -9.1          | 176      | 0.282794                          | 0.000016 | 0.79                | 6.11                  | 0.15 |
| C1-1-15@4.ais  | 4.38                               | 0.07      | 2.90                                | 0.78      | 101.5         | 80.1          | -45.7         | 200      | 0.282777                          | 0.000013 | 0.18                | 5.96                  | 0.16 |

| <i>Sample</i> | $(^{238}\text{U}/^{232}\text{Th})$ | <i>Is</i> | $(^{230}\text{Th}/^{232}\text{Th})$ | <i>Is</i> | <i>Th age</i> | <i>pos Is</i> | <i>neg Is</i> | <i>U</i> | $^{176}\text{Hf}/^{177}\text{Hf}$ | 2SE      | $\epsilon\text{Hf}$ | $\delta^{18}\text{O}$ | 2SE  |
|---------------|------------------------------------|-----------|-------------------------------------|-----------|---------------|---------------|---------------|----------|-----------------------------------|----------|---------------------|-----------------------|------|
| T9'-2@2.ais   | 4.02                               | 0.06      | 1.49                                | 0.21      | 33.3          | 10.5          | -9.6          | 169      | 0.282861                          | 0.000017 | 3.16                | 5.91                  | 0.40 |
| T9'-3@3.ais   | 3.56                               | 0.06      | 1.15                                | 0.12      | 25.8          | 6.7           | -6.3          | 151      | 0.282788                          | 0.000015 | 0.57                | 6.11                  | 0.25 |
| T9'-4@4.ais   | 5.32                               | 0.08      | 2.18                                | 0.30      | 40.8          | 12.0          | -10.8         | 190      | 0.282811                          | 0.000014 | 1.37                | 5.93                  | 0.18 |
| T9'-6@5.ais   | 5.08                               | 0.07      | 1.53                                | 0.20      | 22.4          | 7.6           | -7.1          | 368      | 0.282835                          | 0.000015 | 2.24                | 6.05                  | 0.23 |
| T9'-7@6.ais   | 4.74                               | 0.07      | 1.52                                | 0.16      | 25.7          | 6.9           | -6.5          | 274      | 0.282832                          | 0.000014 | 2.12                | 5.98                  | 0.21 |
| T9'-9@7.ais   | 4.52                               | 0.10      | 1.53                                | 0.17      | 28.0          | 7.9           | -7.4          | 259      | 0.282825                          | 0.000014 | 1.89                | 5.81                  | 0.16 |
| T9'-8@8.ais   | 3.74                               | 0.06      | 1.24                                | 0.13      | 27.5          | 7.3           | -6.8          | 307      | 0.282828                          | 0.000016 | 1.98                | 5.77                  | 0.20 |
| T9'-10@9.ais  | 5.01                               | 0.14      | 1.50                                | 0.26      | 21.8          | 9.3           | -8.6          | 130      | 0.282824                          | 0.000014 | 1.84                | 5.97                  | 0.22 |
| T9'-11@10.ais | 6.89                               | 0.10      | 1.59                                | 0.31      | 11.8          | 7.3           | -6.8          | 120      | 0.282849                          | 0.000014 | 2.74                | 5.87                  | 0.26 |
| T9'-12@11.ais | 4.49                               | 0.10      | 1.56                                | 0.23      | 30.0          | 9.9           | -9.0          | 449      | -                                 | -        | -                   | -                     | -    |

195 Note: “-“ means not collected.

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202 Table S2. SIMS U-Pb dating, O isotope and LA-MC-ICP-MS Lu-Hf isotope results for the DCLZs in the back-arc volcanic rocks.

|                  | U-Th-Pb isotope ratios              |      |                                     |      |                                      |      | Ages (Myr)                           |       |                                     |      |                                     |      | U (ppm) | Th/U | <sup>176</sup> Hf/ <sup>177</sup> Hf | 2SE      | εHf <sub>(0)</sub> | εHf <sub>(t)</sub> | T <sub>DM2</sub> | δ <sup>18</sup> O | 2SE  |
|------------------|-------------------------------------|------|-------------------------------------|------|--------------------------------------|------|--------------------------------------|-------|-------------------------------------|------|-------------------------------------|------|---------|------|--------------------------------------|----------|--------------------|--------------------|------------------|-------------------|------|
|                  | <sup>207</sup> Pb/ <sup>235</sup> U | ±σ%  | <sup>206</sup> Pb/ <sup>238</sup> U | ±σ%  | <sup>207</sup> Pb/ <sup>206</sup> Pb | ±σ%  | <sup>207</sup> Pb/ <sup>206</sup> Pb | ±σ%   | <sup>207</sup> Pb/ <sup>235</sup> U | ±σ%  | <sup>206</sup> Pb/ <sup>238</sup> U | ±σ%  |         |      |                                      |          |                    |                    |                  |                   |      |
| <b>C1@05</b>     | 1.11193                             | 2.88 | 0.1219                              | 1.53 | 0.06613                              | 2.44 | 810.6                                | 50.2  | 759.1                               | 15.5 | <b>741.7</b>                        | 10.7 | 243     | 0.88 | 0.281885                             | 0.000014 | -31.4              | -15.7              | 2635             | 5.76              | 0.13 |
| <b>C1@09</b>     | 1.67616                             | 1.72 | 0.1672                              | 1.55 | 0.07271                              | 0.73 | <b>1005.9</b>                        | 14.8  | 999.5                               | 11.0 | 996.6                               | 14.3 | 843     | 0.45 | 0.282030                             | 0.000012 | -26.2              | -4.9               | 2154             | 7.98              | 0.11 |
| <b>C1@20</b>     | 4.86361                             | 1.62 | 0.3086                              | 1.50 | 0.11431                              | 0.61 | <b>1869.1</b>                        | 11.0  | 1796.0                              | 13.7 | 1733.7                              | 22.8 | 542     | 0.33 | -                                    | -        | -                  | -                  | -                | 10.66             | 0.07 |
| <b>C1@08</b>     | 11.56759                            | 1.60 | 0.4598                              | 1.52 | 0.18245                              | 0.49 | <b>2675.3</b>                        | 8.1   | 2570.1                              | 15.0 | 2438.8                              | 30.9 | 395     | 0.14 | 0.281232                             | 0.000015 | -54.5              | 4.9                | 2837             | 5.74              | 0.15 |
| <b>C1@07</b>     | 12.41889                            | 2.52 | 0.5039                              | 2.19 | 0.17875                              | 1.25 | <b>2641.3</b>                        | 20.5  | 2636.6                              | 24.0 | 2630.4                              | 47.5 | 227     | 0.40 | 0.281244                             | 0.000016 | -54.0              | 4.7                | 2825             | 5.85              | 0.08 |
| <b>C1-2@08</b>   | 7.13741                             | 2.20 | 0.3549                              | 1.95 | 0.14587                              | 1.02 | <b>2298.1</b>                        | 17.3  | 2128.7                              | 19.8 | 1957.8                              | 33.1 | 1042    | 0.22 | -                                    | -        | -                  | -                  | -                | 6.93              | 0.22 |
| <b>C1-2@12</b>   | 5.68635                             | 1.57 | 0.3295                              | 1.50 | 0.12516                              | 0.47 | <b>2031.1</b>                        | 8.3   | 1929.3                              | 13.7 | 1836.0                              | 24.0 | 756     | 0.44 | -                                    | -        | -                  | -                  | -                | 8.53              | 0.28 |
| <b>C1-2@15</b>   | 1.84593                             | 1.58 | 0.1657                              | 1.50 | 0.08081                              | 0.49 | <b>1216.8</b>                        | 9.7   | 1062.0                              | 10.5 | 988.2                               | 13.8 | 1141    | 0.46 | -                                    | -        | -                  | -                  | -                | 4.49              | 0.21 |
| <b>C1-1@05</b>   | 5.28034                             | 1.61 | 0.3233                              | 1.50 | 0.11846                              | 0.58 | <b>1933.1</b>                        | 10.4  | 1865.7                              | 13.9 | 1805.8                              | 23.7 | 1100    | 0.04 | -                                    | -        | -                  | -                  | -                | 6.99              | 0.26 |
| <b>C1-1@07</b>   | 8.65435                             | 1.78 | 0.3813                              | 1.52 | 0.16460                              | 0.92 | <b>2503.5</b>                        | 15.4  | 2302.3                              | 16.3 | 2082.5                              | 27.1 | 172     | 0.82 | 0.281304                             | 0.000013 | -51.9              | 3.5                | 2790             | 8.26              | 0.14 |
| <b>C1-1@15</b>   | 7.70496                             | 1.57 | 0.3711                              | 1.50 | 0.15059                              | 0.46 | <b>2352.6</b>                        | 7.8   | 2197.2                              | 14.2 | 2034.5                              | 26.2 | 1387    | 0.32 | -                                    | -        | -                  | -                  | -                | 7.17              | 0.25 |
| <b>T9@18</b>     | 9.13053                             | 1.57 | 0.3946                              | 1.51 | 0.16784                              | 0.44 | <b>2536.2</b>                        | 7.3   | 2351.2                              | 14.5 | 2143.9                              | 27.6 | 273     | 0.88 | -                                    | -        | -                  | -                  | -                | 5.89              | 0.16 |
| <b>C1@15</b>     | 0.15382                             | 3.61 | 0.0230                              | 1.65 | 0.04843                              | 3.21 | 120.6                                | 74.0  | 145.3                               | 4.9  | <b>146.8</b>                        | 2.4  | 1203    | 2.54 | -                                    | -        | -                  | -                  | -                | 5.83              | 0.09 |
| <b>C1@02</b>     | 0.16207                             | 2.37 | 0.0237                              | 1.52 | 0.04964                              | 1.82 | 178.1                                | 41.9  | 152.5                               | 3.4  | <b>150.9</b>                        | 2.3  | 1636    | 0.46 | 0.282554                             | 0.000015 | -7.7               | -4.6               | 1494             | 5.33              | 0.13 |
| <b>C1@03</b>     | 0.16301                             | 2.38 | 0.0246                              | 1.50 | 0.04815                              | 1.85 | 106.6                                | 43.1  | 153.3                               | 3.4  | <b>156.4</b>                        | 2.3  | 1110    | 0.35 | -                                    | -        | -                  | -                  | -                | 5.59              | 0.16 |
| <b>C1@11</b>     | 0.16186                             | 5.14 | 0.0250                              | 1.66 | 0.04699                              | 4.86 | 48.8                                 | 112.1 | 152.3                               | 7.3  | <b>159.1</b>                        | 2.6  | 765     | 0.47 | -                                    | -        | -                  | -                  | -                | -                 | -    |
| <b>C1-2@05</b>   | 0.26698                             | 1.84 | 0.0375                              | 1.50 | 0.05159                              | 1.07 | 267.1                                | 24.3  | 240.3                               | 3.9  | <b>237.5</b>                        | 3.5  | 745     | 0.51 | 0.282467                             | 0.000017 | -10.8              | -5.7               | 1632             | 8.91              | 0.12 |
| <b>C1-1@14</b>   | 0.15115                             | 7.51 | 0.0253                              | 1.57 | 0.04328                              | 7.35 | -151.4                               | 173.0 | 142.9                               | 10.1 | <b>161.2</b>                        | 2.5  | 446     | 0.44 | 0.282581                             | 0.000022 | -6.8               | -3.3               | 1419             | 8.30              | 0.27 |
| <b>C1-1@17</b>   | 0.45658                             | 1.82 | 0.0592                              | 1.50 | 0.05594                              | 1.03 | 450.0                                | 22.7  | 381.9                               | 5.8  | <b>370.7</b>                        | 5.4  | 2384    | 0.71 | -                                    | -        | -                  | -                  | -                | 6.34              | 0.20 |
| <b>R10-H2@04</b> | 0.11074                             | 2.47 | 0.0169                              | 1.51 | 0.04745                              | 1.95 | 72.0                                 | 45.8  | 106.6                               | 2.5  | <b>108.2</b>                        | 1.6  | 1415    | 1.01 | -                                    | -        | -                  | -                  | -                | -                 | -    |

203 Note: The calculation methods for εHf<sub>(0)</sub>, εHf<sub>(t)</sub>, and T<sub>DM2</sub> are according to the methods of Griffin et al., (2000); “-” means not collected.

204 **Table S3. SIMS trace element results for the LCLZs and DCLZs in the volcanic rocks (ppm).**

|                       | La   | Ce    | Pr   | Nd    | Sm    | Eu   | Gd    | Tb    | Dy  | Ho  | Er  | Tm  | Yb   | Lu  | Y    | Th  | U    | Hf    | Th/U | <sup>a</sup> Ti | <sup>b</sup> T (°C) |
|-----------------------|------|-------|------|-------|-------|------|-------|-------|-----|-----|-----|-----|------|-----|------|-----|------|-------|------|-----------------|---------------------|
| C1-1@1                | 0.06 | 7.47  | 0.03 | 0.61  | 1.71  | 0.31 | 10.98 | 4.69  | 59  | 26  | 126 | 28  | 266  | 60  | 778  | 63  | 129  | 11425 | 0.49 | 6.21            | 701                 |
| C1-2@2                | 0.19 | 9.34  | 0.16 | 2.15  | 4.86  | 0.79 | 27.63 | 11.63 | 141 | 60  | 266 | 57  | 515  | 115 | 1709 | 125 | 185  | 11199 | 0.68 | 5.08            | 685                 |
| C1-3@3                | 0.06 | 6.82  | 0.02 | 0.52  | 1.51  | 0.32 | 10.30 | 4.43  | 58  | 26  | 121 | 27  | 259  | 59  | 750  | 57  | 113  | 11939 | 0.50 | 5.28            | 688                 |
| C1-4@4                | 0.06 | 7.90  | 0.09 | 2.09  | 4.72  | 0.71 | 25.80 | 10.23 | 128 | 53  | 237 | 51  | 460  | 103 | 1541 | 101 | 149  | 11034 | 0.67 | 5.36            | 689                 |
| C1-6@5                | 1.36 | 18.38 | 0.67 | 6.20  | 8.06  | 0.77 | 43.31 | 16.20 | 183 | 70  | 297 | 62  | 528  | 113 | 2163 | 335 | 688  | 10883 | 0.49 | 3.85            | 663                 |
| C1-5@6                | 0.16 | 13.98 | 0.15 | 2.05  | 4.75  | 0.86 | 29.49 | 13.14 | 168 | 74  | 337 | 75  | 681  | 158 | 2161 | 212 | 283  | 10163 | 0.75 | 8.77            | 729                 |
| C1-7@7                | 0.04 | 7.82  | 0.04 | 0.65  | 2.03  | 0.33 | 12.59 | 5.71  | 75  | 33  | 157 | 36  | 333  | 80  | 1002 | 71  | 139  | 10568 | 0.51 | 5.79            | 695                 |
| C1-8@8                | 0.22 | 8.04  | 0.08 | 1.16  | 2.41  | 0.48 | 15.43 | 6.99  | 88  | 39  | 186 | 42  | 390  | 93  | 1211 | 66  | 131  | 10300 | 0.50 | 6.32            | 702                 |
| <sup>c</sup> C1-9@9   | 0.07 | 6.45  | 0.04 | 0.37  | 1.30  | 0.23 | 8.07  | 3.62  | 47  | 21  | 98  | 23  | 204  | 50  | 640  | 44  | 103  | 11384 | 0.43 | 6.31            | 702                 |
| <sup>d</sup> C1-10@10 | 0.06 | 9.29  | 0.20 | 2.84  | 2.73  | 0.95 | 9.30  | 3.15  | 33  | 13  | 57  | 13  | 122  | 31  | 424  | 59  | 99   | 9731  | 0.59 | 3.28            | 651                 |
| C1-11@11              | 1.51 | 18.90 | 0.36 | 2.29  | 2.48  | 0.46 | 16.60 | 8.53  | 124 | 63  | 342 | 87  | 914  | 225 | 1956 | 377 | 977  | 11130 | 0.39 | 34.83           | 864                 |
| C1-12@12              | 0.14 | 16.70 | 0.24 | 4.16  | 8.27  | 1.45 | 45.58 | 18.85 | 224 | 92  | 405 | 86  | 757  | 168 | 2679 | 336 | 325  | 10931 | 1.03 | 6.53            | 705                 |
| C1-13@13              | 0.09 | 21.77 | 0.35 | 6.66  | 14.49 | 3.11 | 80.87 | 33.26 | 390 | 156 | 671 | 138 | 1235 | 261 | 4270 | 462 | 472  | 10451 | 0.98 | 5.92            | 697                 |
| C1-14@14              | 0.77 | 9.70  | 0.25 | 2.15  | 3.33  | 0.74 | 13.44 | 4.37  | 43  | 15  | 66  | 14  | 122  | 29  | 491  | 102 | 364  | 10382 | 0.28 | 24.08           | 824                 |
| C1-15@15              | 0.09 | 7.06  | 0.04 | 0.68  | 1.43  | 0.24 | 9.46  | 4.28  | 53  | 23  | 109 | 25  | 227  | 53  | 733  | 64  | 126  | 10554 | 0.51 | 5.48            | 691                 |
| C1-1-1@1              | 2.75 | 26.03 | 0.96 | 4.77  | 3.57  | 0.47 | 16.14 | 5.83  | 60  | 24  | 102 | 23  | 195  | 45  | 762  | 84  | 110  | 11202 | 0.76 | 33.30           | 859                 |
| C1-1-2@2              | 0.67 | 22.41 | 0.25 | 2.14  | 1.63  | 0.46 | 8.60  | 3.18  | 33  | 13  | 53  | 13  | 118  | 28  | 395  | 82  | 160  | 12482 | 0.51 | 14.06           | 772                 |
| C1-1-3@3              | 0.93 | 6.80  | 0.35 | 1.57  | 1.71  | 0.34 | 10.69 | 4.55  | 55  | 21  | 107 | 27  | 257  | 63  | 700  | 39  | 481  | 11942 | 0.08 | 19.81           | 805                 |
| C1-1-4@4              | 0.60 | 13.48 | 0.28 | 1.63  | 1.48  | 0.39 | 9.03  | 4.01  | 47  | 20  | 96  | 23  | 213  | 51  | 627  | 107 | 434  | 12016 | 0.25 | 16.51           | 787                 |
| C1-1-5@5              | 2.28 | 12.36 | 0.63 | 3.03  | 2.29  | 0.36 | 11.77 | 5.76  | 68  | 30  | 139 | 32  | 284  | 68  | 912  | 66  | 121  | 10329 | 0.54 | 16.68           | 788                 |
| C1-1-6@6              | 8.97 | 78.13 | 3.40 | 20.64 | 15.39 | 2.23 | 59.17 | 22.47 | 265 | 107 | 487 | 107 | 959  | 210 | 3228 | 770 | 1089 | 10714 | 0.71 | 444.85          | 1238                |
| C1-1-7@7              | 0.32 | 8.53  | 0.16 | 1.07  | 2.12  | 0.34 | 12.58 | 5.47  | 71  | 30  | 142 | 34  | 301  | 70  | 908  | 80  | 149  | 10573 | 0.53 | 17.99           | 795                 |
| C1-1-8@8              | 8.15 | 24.00 | 2.17 | 10.15 | 5.67  | 0.66 | 18.66 | 6.75  | 73  | 30  | 126 | 27  | 235  | 52  | 882  | 132 | 315  | 9441  | 0.42 | 97.33           | 990                 |
| C1-1-9@9              | 0.52 | 37.20 | 0.33 | 2.99  | 5.61  | 1.32 | 22.78 | 8.25  | 88  | 30  | 125 | 27  | 226  | 49  | 950  | 176 | 660  | 9515  | 0.27 | 12.25           | 759                 |

**Table S3 (continued)**

|            |       |        |       |        |        |       |        |       |     |     |     |     |      |     |      |     |      |       |      |        |      |
|------------|-------|--------|-------|--------|--------|-------|--------|-------|-----|-----|-----|-----|------|-----|------|-----|------|-------|------|--------|------|
| C1-1-10@10 | 0.13  | 13.09  | 0.23  | 3.71   | 7.41   | 1.23  | 40.21  | 16.88 | 200 | 80  | 350 | 77  | 666  | 151 | 2368 | 176 | 222  | 9789  | 0.79 | 7.22   | 713  |
| C1-1-11@11 | 2.30  | 13.31  | 0.56  | 2.55   | 2.05   | 0.42  | 11.13  | 4.75  | 64  | 27  | 125 | 30  | 264  | 63  | 821  | 62  | 105  | 9944  | 0.59 | 47.96  | 900  |
| C1-2-9@1   | 0.21  | 8.20   | 0.07  | 0.93   | 2.09   | 0.47  | 14.43  | 6.14  | 80  | 33  | 160 | 38  | 337  | 79  | 1048 | 81  | 170  | 10965 | 0.47 | 13.11  | 765  |
| C1-2-8@2   | 0.45  | 7.59   | 0.15  | 0.80   | 1.63   | 0.33  | 10.82  | 4.77  | 58  | 26  | 121 | 28  | 261  | 62  | 791  | 45  | 98   | 10425 | 0.46 | 11.26  | 751  |
| C1-2-7@3   | 0.71  | 10.17  | 0.25  | 1.02   | 2.04   | 0.52  | 12.75  | 5.68  | 70  | 31  | 143 | 32  | 291  | 70  | 912  | 118 | 177  | 10469 | 0.67 | 23.33  | 821  |
| C1-2-6@4   | 0.38  | 8.12   | 0.16  | 1.48   | 3.04   | 0.52  | 17.78  | 7.71  | 95  | 41  | 189 | 42  | 379  | 89  | 1234 | 67  | 122  | 10344 | 0.55 | 8.04   | 722  |
| C1-2-5@5   | 1.91  | 11.19  | 0.79  | 5.02   | 4.07   | 0.56  | 16.15  | 6.25  | 76  | 33  | 156 | 37  | 328  | 80  | 1024 | 65  | 123  | 9500  | 0.53 | 44.62  | 892  |
| C1-2-4@6   | 0.56  | 10.73  | 0.35  | 3.96   | 4.97   | 0.73  | 27.63  | 10.55 | 123 | 49  | 222 | 47  | 436  | 98  | 1490 | 195 | 592  | 10891 | 0.33 | 8.79   | 730  |
| C1-2-3@7   | 45.37 | 308.62 | 55.90 | 313.19 | 172.04 | 51.27 | 211.60 | 55.61 | 443 | 117 | 439 | 96  | 865  | 182 | 3631 | 274 | 2261 | 19873 | 0.12 | 26.09  | 833  |
| C1-2-2@8   | 4.85  | 46.33  | 2.78  | 16.53  | 30.56  | 18.83 | 148.93 | 51.92 | 382 | 105 | 389 | 75  | 644  | 140 | 3082 | 359 | 419  | 11683 | 0.86 | 387.25 | 1211 |
| C1-2-1@9   | 0.45  | 14.62  | 0.49  | 3.73   | 5.76   | 1.29  | 30.35  | 11.45 | 138 | 54  | 245 | 52  | 457  | 99  | 1579 | 201 | 658  | 14198 | 0.31 | 8.25   | 724  |
| T9'-2@2    | 1.40  | 14.71  | 2.10  | 18.27  | 18.07  | 3.74  | 64.39  | 21.84 | 217 | 75  | 300 | 63  | 513  | 113 | 2250 | 229 | 502  | 9389  | 0.46 | 7.95   | 721  |
| T9'-3@3    | 16.79 | 90.90  | 15.72 | 92.98  | 58.39  | 19.80 | 115    | 36.94 | 333 | 112 | 500 | 124 | 1197 | 268 | 3604 | 169 | 809  | 12452 | 0.21 | 1553   | 1529 |
| T9'-4@4    | 1.08  | 74.37  | 0.68  | 6.88   | 8.26   | 3.41  | 29.83  | 10.43 | 109 | 42  | 192 | 43  | 391  | 96  | 1382 | 375 | 411  | 9648  | 0.91 | 27.69  | 839  |
| T9'-5@5    | 1.61  | 25.83  | 0.84  | 5.75   | 7.51   | 4.10  | 34.86  | 14.94 | 148 | 55  | 232 | 56  | 527  | 123 | 1648 | 402 | 953  | 12060 | 0.42 | 24.74  | 827  |
| T9'-6@6    | 7.03  | 43.66  | 2.81  | 17.53  | 17.77  | 9.92  | 70.67  | 23.03 | 207 | 59  | 206 | 39  | 337  | 76  | 1879 | 128 | 200  | 11646 | 0.64 | 93.94  | 985  |
| T9'-7@7    | 0.46  | 12.02  | 0.49  | 5.06   | 6.89   | 1.60  | 30.68  | 11.14 | 122 | 49  | 213 | 46  | 413  | 98  | 1487 | 134 | 173  | 9308  | 0.77 | 9.58   | 737  |
| T9'-8@8    | 1.00  | 113.69 | 0.96  | 6.35   | 7.48   | 2.12  | 31.71  | 11.32 | 130 | 54  | 253 | 58  | 533  | 124 | 1761 | 477 | 383  | 10899 | 1.24 | 24.38  | 826  |
| T9'-9@9    | 0.14  | 7.66   | 0.16  | 2.33   | 4.75   | 0.75  | 27.84  | 11.87 | 142 | 61  | 276 | 61  | 534  | 122 | 1780 | 131 | 228  | 10462 | 0.57 | 5.98   | 698  |
| T9'-10@10  | 0.15  | 10.38  | 0.17  | 3.21   | 7.40   | 1.16  | 41.25  | 17.66 | 215 | 89  | 399 | 88  | 737  | 169 | 2573 | 221 | 334  | 10677 | 0.66 | 21.12  | 811  |
| T9'-11@11  | 0.46  | 13.45  | 0.18  | 1.32   | 3.19   | 0.55  | 21.68  | 9.65  | 129 | 55  | 258 | 58  | 529  | 121 | 1601 | 320 | 414  | 10632 | 0.77 | 23.21  | 821  |
| T9'-12@12  | 0.76  | 13.11  | 0.19  | 1.78   | 2.81   | 0.44  | 19.63  | 8.56  | 113 | 52  | 250 | 59  | 536  | 131 | 1589 | 144 | 310  | 10492 | 0.46 | 41.03  | 882  |
| T9'-13@13  | 1.52  | 14.09  | 0.30  | 2.12   | 2.76   | 0.53  | 18.46  | 8.78  | 116 | 54  | 261 | 63  | 583  | 138 | 1640 | 147 | 307  | 9863  | 0.48 | 30.25  | 848  |
| T9'-14@14  | 3.31  | 20.19  | 1.00  | 4.97   | 4.24   | 0.59  | 22.27  | 9.80  | 128 | 60  | 286 | 65  | 605  | 144 | 1754 | 194 | 356  | 11002 | 0.55 | 23.28  | 821  |
| T9'-15@15  | 0.45  | 14.19  | 0.24  | 2.50   | 4.92   | 0.78  | 31.25  | 13.52 | 169 | 76  | 350 | 79  | 710  | 165 | 2199 | 228 | 379  | 10684 | 0.60 | 10.55  | 746  |

**Table S3 (continued)**

|              |       |       |      |       |       |      |        |       |     |     |      |     |      |     |       |      |      |       |      |        |      |
|--------------|-------|-------|------|-------|-------|------|--------|-------|-----|-----|------|-----|------|-----|-------|------|------|-------|------|--------|------|
| T9'-16@16    | 1.47  | 14.91 | 0.68 | 4.67  | 5.83  | 0.64 | 32.67  | 13.91 | 171 | 72  | 334  | 73  | 639  | 150 | 2123  | 214  | 348  | 11054 | 0.61 | 3.87   | 664  |
| T9'-17@17    | 0.15  | 11.16 | 0.29 | 3.61  | 7.98  | 1.18 | 45.44  | 18.92 | 234 | 97  | 429  | 92  | 798  | 183 | 2807  | 242  | 332  | 10351 | 0.73 | 19.89  | 805  |
| T9'-18@18    | 1.26  | 30.30 | 0.36 | 2.12  | 2.28  | 0.81 | 14.45  | 5.65  | 75  | 32  | 166  | 40  | 377  | 97  | 1042  | 166  | 330  | 10876 | 0.50 | 17.91  | 795  |
| T9'-19@19    | 0.69  | 13.80 | 0.19 | 2.08  | 4.72  | 0.52 | 27.58  | 11.62 | 153 | 66  | 309  | 70  | 618  | 149 | 1943  | 243  | 373  | 10699 | 0.65 | 22.91  | 819  |
| T9'-20@20    | 0.47  | 8.95  | 0.10 | 1.17  | 2.08  | 0.45 | 13.29  | 6.45  | 82  | 39  | 195  | 48  | 445  | 111 | 1202  | 85   | 207  | 11320 | 0.41 | 110.71 | 1008 |
| T9'-21@21    | 0.14  | 8.67  | 0.11 | 1.26  | 2.70  | 0.36 | 19.19  | 8.19  | 110 | 47  | 224  | 49  | 456  | 109 | 1410  | 116  | 231  | 10884 | 0.50 | 13.23  | 766  |
| T9'-22@22    | 3.07  | 13.11 | 0.68 | 3.61  | 2.97  | 0.71 | 17.21  | 7.85  | 96  | 43  | 205  | 47  | 428  | 102 | 1289  | 99   | 205  | 8154  | 0.48 | 84.70  | 971  |
| T9'-23@23    | 0.37  | 12.77 | 0.16 | 2.30  | 4.44  | 0.82 | 30.63  | 13.38 | 170 | 75  | 355  | 83  | 721  | 171 | 2229  | 185  | 345  | 10499 | 0.54 | 24.76  | 827  |
| T9'-24@24    | 2.84  | 93.82 | 1.41 | 18.68 | 34.64 | 3.80 | 197.81 | 77.17 | 906 | 362 | 1571 | 327 | 2676 | 577 | 10360 | 2278 | 1807 | 7754  | 1.26 | 37.44  | 872  |
| R10-H2-1@1   | 0.39  | 9.48  | 0.24 | 2.17  | 4.73  | 0.78 | 31.98  | 13.20 | 158 | 67  | 316  | 67  | 574  | 133 | 1943  | 160  | 253  | 10262 | 0.63 | 12.40  | 760  |
| R10-H2-2@2   | 0.58  | 12.28 | 0.23 | 2.97  | 6.45  | 1.36 | 42.59  | 17.29 | 208 | 88  | 401  | 87  | 752  | 171 | 2562  | 231  | 339  | 9789  | 0.68 | 13.91  | 771  |
| R10-H2-3@3   | 3.16  | 21.66 | 0.81 | 5.41  | 4.65  | 0.57 | 24.24  | 10.47 | 135 | 59  | 275  | 61  | 581  | 124 | 1690  | 288  | 414  | 10514 | 0.70 | 45.50  | 894  |
| R10-H2-4@4   | 0.44  | 13.80 | 0.15 | 1.59  | 3.32  | 0.52 | 22.45  | 9.53  | 128 | 56  | 264  | 63  | 555  | 132 | 1646  | 231  | 392  | 11172 | 0.59 | 10.13  | 742  |
| R10-H2-5@5   | 3.25  | 15.13 | 1.19 | 5.41  | 3.95  | 0.52 | 19.17  | 7.78  | 101 | 42  | 192  | 45  | 386  | 92  | 1232  | 103  | 176  | 11069 | 0.58 | 5.83   | 696  |
| R10-H2-6@6   | 0.67  | 35.00 | 0.63 | 6.66  | 13.65 | 2.28 | 69.49  | 28.15 | 338 | 143 | 636  | 139 | 1237 | 274 | 4264  | 795  | 826  | 10832 | 0.96 | 8.06   | 722  |
| R10-H2-7@7   | 0.77  | 16.20 | 0.26 | 3.55  | 6.51  | 1.37 | 43.63  | 17.54 | 208 | 89  | 391  | 85  | 750  | 169 | 2582  | 338  | 422  | 10159 | 0.80 | 46.73  | 897  |
| R10-H2-8@8   | 0.25  | 9.38  | 0.11 | 0.88  | 2.80  | 0.39 | 14.55  | 6.68  | 87  | 38  | 177  | 39  | 359  | 85  | 1123  | 131  | 233  | 10610 | 0.56 | 12.67  | 762  |
| R10-H2-9@9   | 0.16  | 9.54  | 0.16 | 1.53  | 3.47  | 0.61 | 24.47  | 9.91  | 125 | 53  | 259  | 56  | 511  | 122 | 1609  | 128  | 250  | 10891 | 0.51 | 11.66  | 755  |
| R10-H2-10@10 | 0.58  | 15.81 | 0.38 | 3.07  | 5.92  | 0.82 | 36.57  | 15.29 | 199 | 83  | 369  | 84  | 718  | 163 | 2383  | 305  | 420  | 10617 | 0.72 | 7.98   | 721  |
| R10-H2-11@11 | 0.26  | 12.55 | 0.17 | 2.75  | 5.93  | 0.63 | 34.17  | 14.91 | 179 | 77  | 344  | 75  | 665  | 145 | 2170  | 240  | 386  | 11379 | 0.62 | 11.21  | 751  |
| R10-H2-12@12 | 15.19 | 51.02 | 4.88 | 26.87 | 11.03 | 1.42 | 47.92  | 18.78 | 221 | 91  | 411  | 90  | 766  | 177 | 2668  | 305  | 445  | 10284 | 0.69 | 6.84   | 709  |
| R10-H2-13@13 | 0.18  | 4.30  | 0.16 | 2.84  | 6.04  | 0.39 | 38.28  | 15.38 | 182 | 70  | 302  | 62  | 540  | 115 | 2125  | 170  | 319  | 11624 | 0.53 | 11.46  | 753  |
| R10-H2-14@14 | 0.15  | 14.96 | 0.29 | 3.65  | 6.72  | 1.08 | 40.37  | 16.93 | 214 | 91  | 406  | 92  | 836  | 182 | 2593  | 316  | 431  | 10307 | 0.73 | 10.92  | 749  |
| R10-H2-15@15 | 0.48  | 11.77 | 0.17 | 1.13  | 2.51  | 0.54 | 17.65  | 8.59  | 108 | 49  | 237  | 55  | 502  | 116 | 1465  | 208  | 298  | 10351 | 0.70 | 17.90  | 795  |
| R10-H2-16@16 | 1.32  | 11.89 | 0.46 | 2.22  | 4.11  | 0.51 | 25.62  | 10.09 | 135 | 57  | 269  | 60  | 531  | 122 | 1711  | 183  | 302  | 10025 | 0.60 | 28.45  | 842  |

**Table S3 (continued)**

|              |      |       |      |      |      |      |       |       |     |    |     |    |     |     |      |     |     |       |      |       |     |
|--------------|------|-------|------|------|------|------|-------|-------|-----|----|-----|----|-----|-----|------|-----|-----|-------|------|-------|-----|
| R10-H2-17@17 | 0.43 | 8.59  | 0.15 | 1.18 | 2.31 | 0.38 | 13.73 | 5.83  | 83  | 38 | 185 | 43 | 400 | 93  | 1144 | 111 | 278 | 10691 | 0.40 | 14.35 | 774 |
| R10-H2-18@18 | 1.10 | 12.41 | 0.35 | 3.54 | 4.22 | 0.80 | 26.87 | 11.44 | 147 | 65 | 289 | 65 | 582 | 133 | 1866 | 175 | 304 | 10543 | 0.58 | 17.09 | 790 |
| R10-H2-19@19 | 0.30 | 8.04  | 0.13 | 1.18 | 3.77 | 0.56 | 20.38 | 8.86  | 115 | 50 | 237 | 51 | 468 | 105 | 1457 | 121 | 221 | 11061 | 0.55 | 5.64  | 693 |
| R10-H2-20@20 | 0.51 | 10.20 | 0.20 | 1.36 | 2.22 | 0.45 | 14.36 | 5.90  | 82  | 36 | 181 | 42 | 396 | 99  | 1126 | 113 | 237 | 10810 | 0.48 | 24.63 | 827 |
| R10-H2-21@21 | 1.20 | 11.47 | 0.25 | 1.95 | 3.08 | 0.65 | 19.28 | 8.43  | 114 | 49 | 226 | 55 | 486 | 114 | 1504 | 194 | 300 | 10092 | 0.65 | 58.57 | 924 |
| R10-H2-22@22 | 0.18 | 14.99 | 0.20 | 2.67 | 5.94 | 0.85 | 35.84 | 15.18 | 195 | 85 | 391 | 85 | 763 | 173 | 2490 | 264 | 408 | 10181 | 0.65 | 7.75  | 719 |
| R10-H2-23@23 | 2.67 | 19.58 | 0.80 | 5.49 | 6.02 | 0.74 | 29.00 | 12.59 | 155 | 69 | 315 | 68 | 617 | 141 | 2014 | 237 | 370 | 10529 | 0.64 | 10.57 | 746 |

205 Note: a) Ti<sub>91500</sub> corrected; b) T (°C)  $a_{\text{TiO}_2}=1$ ; c) C1-9@9 and C1-10@10 are the results for the representative LCLZ and its DCLZ core, respectively, as shown in Fig. 3.

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207 **Table S4.** Sampling locations of the studied volcanic rocks from the Okinawa Trough.

| Sample        | Latitude, N   | Longitude, E   | Depth, m | Rock-type |
|---------------|---------------|----------------|----------|-----------|
| <b>C1</b>     | 24°54'07.027" | 122°32'33.783" | 1176     | Dacite    |
| <b>T9'</b>    | 24°50'57.774" | 122°41'55.877" | 1382     | Rhyolite  |
| <b>R10-H2</b> | 24°50'47.876" | 122°42'01.783" | 1378     | Rhyolite  |

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**Table S5.** U-Th isotope compositions for the reference AS3 and Qinghu zircon standards.

| <b>Standards</b> | <b>(<sup>230</sup>Th/<sup>232</sup>Th)</b> | <b>1s</b> | <b>(<sup>238</sup>U/<sup>232</sup>Th)</b> | <b>1s</b> | <b>(<sup>230</sup>Th/<sup>238</sup>U)</b> | <b>1s</b> |
|------------------|--|-----------|---|-----------|---|-----------|
| as3@1.ais        | 2.980                                      | 0.039     | 2.635                                     | 0.037     | 1.131                                     | 0.022     |
| as3@2.ais        | 2.964                                      | 0.049     | 2.706                                     | 0.106     | 1.095                                     | 0.047     |
| as3@3.ais        | 3.030                                      | 0.055     | 2.749                                     | 0.037     | 1.102                                     | 0.025     |
| as3@4.ais        | 4.991                                      | 0.121     | 4.864                                     | 0.065     | 1.026                                     | 0.028     |
| as3@5.ais        | 4.282                                      | 0.082     | 4.187                                     | 0.083     | 1.023                                     | 0.028     |
| as3@6.ais        | 4.569                                      | 0.175     | 4.002                                     | 0.079     | 1.142                                     | 0.049     |
| qinghu@1.ais     | 5.272                                      | 0.148     | 5.054                                     | 0.103     | 1.043                                     | 0.036     |
| qinghu@2.ais     | 14.168                                     | 0.381     | 13.061                                    | 0.378     | 1.085                                     | 0.043     |
| qinghu@3.ais     | 5.021                                      | 0.210     | 5.013                                     | 0.099     | 1.002                                     | 0.046     |
| qinghu@4.ais     | 5.877                                      | 0.181     | 5.672                                     | 0.127     | 1.036                                     | 0.039     |
| qinghu@5.ais     | 5.837                                      | 0.206     | 5.329                                     | 0.107     | 1.095                                     | 0.044     |
| qinghu@6.ais     | 5.648                                      | 0.261     | 5.156                                     | 0.106     | 1.095                                     | 0.055     |
| qinghu@7.ais     | 7.662                                      | 0.269     | 6.472                                     | 0.129     | 1.184                                     | 0.048     |
| qinghu@8.ais     | 7.804                                      | 0.373     | 7.386                                     | 0.148     | 1.057                                     | 0.055     |
| qinghu@9.ais     | 6.740                                      | 0.370     | 5.687                                     | 0.113     | 1.185                                     | 0.069     |
| qinghu@10.ais    | 7.232                                      | 0.354     | 6.041                                     | 0.120     | 1.197                                     | 0.063     |
| qinghu@11.ais    | 7.635                                      | 0.194     | 7.160                                     | 0.142     | 1.066                                     | 0.034     |
| qinghu@12.ais    | 7.442                                      | 0.188     | 6.832                                     | 0.135     | 1.089                                     | 0.035     |
| qinghu@13.ais    | 5.970                                      | 0.205     | 5.777                                     | 0.137     | 1.033                                     | 0.043     |
| qinghu@14.ais    | 6.819                                      | 0.463     | 6.785                                     | 0.135     | 1.005                                     | 0.071     |
| qinghu@15.ais    | 9.517                                      | 0.268     | 8.646                                     | 0.172     | 1.101                                     | 0.038     |
| qinghu@16.ais    | 7.821                                      | 0.282     | 7.509                                     | 0.152     | 1.042                                     | 0.043     |
| qinghu@17.ais    | 6.576                                      | 0.180     | 6.372                                     | 0.126     | 1.032                                     | 0.035     |
| qinghu@18.ais    | 5.317                                      | 0.171     | 4.837                                     | 0.098     | 1.099                                     | 0.042     |
| qinghu@19.ais    | 7.502                                      | 0.234     | 7.122                                     | 0.141     | 1.053                                     | 0.039     |
| qinghu@20.ais    | 6.228                                      | 0.239     | 5.578                                     | 0.129     | 1.116                                     | 0.050     |
| qinghu@21.ais    | 6.009                                      | 0.147     | 5.769                                     | 0.118     | 1.042                                     | 0.033     |
| qinghu@22.ais    | 6.578                                      | 0.186     | 6.073                                     | 0.124     | 1.083                                     | 0.038     |
| qinghu@23.ais    | 6.146                                      | 0.188     | 6.088                                     | 0.125     | 1.010                                     | 0.037     |
| qinghu@24.ais    | 5.738                                      | 0.244     | 5.517                                     | 0.110     | 1.040                                     | 0.049     |
| qinghu@25.ais    | 6.350                                      | 0.270     | 5.947                                     | 0.121     | 1.068                                     | 0.050     |

**Table S6.** U-Pb dating results for the Qinghu zircon standard measured by SIMS.

| Sample/<br>spot # | [U]<br>ppm | [Th]<br>ppm | Th/U<br>meas | f <sub>206</sub> % | <sup>207</sup> Pb<br><sup>235</sup> U | ±<br>% | <sup>206</sup> Pb<br><sup>238</sup> U | ±<br>% | <sup>207</sup> Pb<br><sup>206</sup> Pb | ±<br>% | t <sub>207/235</sub><br>/Ma | ±   | t <sub>206/238</sub><br>/Ma | ±   |
|-------------------|------------|-------------|--------------|--------------------|---------------------------------------|--------|---------------------------------------|--------|--|--------|-----------------------------|-----|-----------------------------|-----|
| Qinghu@1          | 772        | 337         | 0.44         | 0.54               | 0.1707                                | 2.73   | 0.0251                                | 1.64   | 0.0493                                 | 2.18   | 160.0                       | 4.0 | 159.9                       | 2.6 |
| Qinghu@2          | 982        | 456         | 0.46         | 0.27               | 0.1746                                | 2.45   | 0.0253                                | 1.57   | 0.0501                                 | 1.88   | 163.4                       | 3.7 | 161.0                       | 2.5 |
| Qinghu@3          | 1431       | 678         | 0.47         | 0.23               | 0.1720                                | 2.41   | 0.0258                                | 1.51   | 0.0484                                 | 1.87   | 161.2                       | 3.6 | 164.0                       | 2.4 |
| Qinghu@4          | 1909       | 1105        | 0.58         | 0.23               | 0.1698                                | 2.07   | 0.0252                                | 1.56   | 0.0489                                 | 1.36   | 159.3                       | 3.1 | 160.5                       | 2.5 |
| Qinghu@5          | 1119       | 500         | 0.45         | 0.32               | 0.1608                                | 3.21   | 0.0242                                | 1.68   | 0.0482                                 | 2.73   | 151.4                       | 4.5 | 154.2                       | 2.6 |
| Qinghu@6          | 1108       | 506         | 0.46         | 0.15               | 0.1656                                | 2.49   | 0.0245                                | 1.53   | 0.0490                                 | 1.97   | 155.6                       | 3.6 | 156.0                       | 2.4 |
| Qinghu@7          | 1018       | 606         | 0.59         | 0.27               | 0.1713                                | 2.66   | 0.0250                                | 1.54   | 0.0497                                 | 2.17   | 160.5                       | 4.0 | 159.0                       | 2.4 |
| Qinghu@8          | 3216       | 2157        | 0.67         | 0.07               | 0.1709                                | 2.30   | 0.0251                                | 1.87   | 0.0494                                 | 1.34   | 160.2                       | 3.4 | 159.9                       | 3.0 |
| Qinghu@9          | 1607       | 728         | 0.45         | 0.30               | 0.1717                                | 2.06   | 0.0253                                | 1.53   | 0.0492                                 | 1.38   | 160.9                       | 3.1 | 161.2                       | 2.4 |
| Qinghu@10         | 997        | 385         | 0.39         | 0.07               | 0.1683                                | 2.37   | 0.0248                                | 1.50   | 0.0493                                 | 1.83   | 157.9                       | 3.5 | 157.6                       | 2.3 |
| Qinghu@11         | 1802       | 897         | 0.50         | 0.04               | 0.1702                                | 2.00   | 0.0251                                | 1.53   | 0.0492                                 | 1.29   | 159.6                       | 3.0 | 159.7                       | 2.4 |
| Qinghu@12         | 1465       | 626         | 0.43         | 0.10               | 0.1766                                | 1.99   | 0.0258                                | 1.51   | 0.0497                                 | 1.30   | 165.1                       | 3.0 | 163.9                       | 2.4 |
| Qinghu@13         | 756        | 231         | 0.31         | 0.09               | 0.1716                                | 2.42   | 0.0254                                | 1.56   | 0.0489                                 | 1.85   | 160.8                       | 3.6 | 161.9                       | 2.5 |
| Qinghu@14         | 1880       | 757         | 0.40         | 0.04               | 0.1708                                | 1.99   | 0.0250                                | 1.52   | 0.0495                                 | 1.30   | 160.1                       | 3.0 | 159.2                       | 2.4 |
| Qinghu@15         | 791        | 253         | 0.32         | 0.12               | 0.1689                                | 2.37   | 0.0253                                | 1.52   | 0.0484                                 | 1.82   | 158.4                       | 3.5 | 161.1                       | 2.4 |
| Qinghu@16         | 1170       | 472         | 0.40         | 0.27               | 0.1629                                | 2.86   | 0.0247                                | 1.52   | 0.0478                                 | 2.42   | 153.2                       | 4.1 | 157.3                       | 2.4 |
| Qinghu@17         | 1671       | 698         | 0.42         | 0.25               | 0.1642                                | 2.66   | 0.0250                                | 1.55   | 0.0476                                 | 2.16   | 154.4                       | 3.8 | 159.3                       | 2.4 |
| Qinghu@18         | 1031       | 435         | 0.42         | 0.16               | 0.1726                                | 2.24   | 0.0254                                | 1.52   | 0.0493                                 | 1.64   | 161.7                       | 3.4 | 161.5                       | 2.4 |
| Qinghu@19         | 3071       | 2066        | 0.67         | 0.01               | 0.1693                                | 1.70   | 0.0249                                | 1.67   | 0.0493                                 | 0.31   | 158.8                       | 2.5 | 158.5                       | 2.6 |
| Qinghu@20         | 1947       | 1043        | 0.54         | 0.13               | 0.1663                                | 1.64   | 0.0245                                | 1.56   | 0.0493                                 | 0.51   | 156.2                       | 2.4 | 155.9                       | 2.4 |
| Qinghu@21         | 1636       | 709         | 0.43         | 0.02               | 0.1708                                | 1.56   | 0.0250                                | 1.50   | 0.0495                                 | 0.42   | 160.1                       | 2.3 | 159.3                       | 2.4 |
| Qinghu@22         | 950        | 349         | 0.37         | 0.03               | 0.1723                                | 1.63   | 0.0253                                | 1.52   | 0.0495                                 | 0.57   | 161.4                       | 2.4 | 160.8                       | 2.4 |
| Qinghu@24         | 3071       | 2066        | 0.67         | 0.01               | 0.1693                                | 1.70   | 0.0249                                | 1.67   | 0.0493                                 | 0.31   | 158.8                       | 2.5 | 158.5                       | 2.6 |
| Qinghu@25         | 1947       | 1043        | 0.54         | 0.13               | 0.1663                                | 1.64   | 0.0245                                | 1.56   | 0.0493                                 | 0.51   | 156.2                       | 2.4 | 155.9                       | 2.4 |
| Qinghu@26         | 1636       | 709         | 0.43         | 0.02               | 0.1708                                | 1.56   | 0.0250                                | 1.50   | 0.0495                                 | 0.42   | 160.1                       | 2.3 | 159.3                       | 2.4 |
| Qinghu@27         | 950        | 349         | 0.37         | 0.03               | 0.1723                                | 1.63   | 0.0253                                | 1.52   | 0.0495                                 | 0.57   | 161.4                       | 2.4 | 160.8                       | 2.4 |
| Qinghu@28         | 1410       | 762         | 0.54         | 0.01               | 0.1672                                | 1.83   | 0.0246                                | 1.78   | 0.0493                                 | 0.45   | 157.0                       | 2.7 | 156.7                       | 2.7 |
| Qinghu@29         | 992        | 378         | 0.38         | 0.82               | 0.1707                                | 2.56   | 0.0251                                | 1.51   | 0.0493                                 | 2.07   | 160.1                       | 3.8 | 159.9                       | 2.4 |
| Qinghu@30         | 1283       | 458         | 0.36         | 0.02               | 0.1688                                | 1.58   | 0.0251                                | 1.50   | 0.0489                                 | 0.47   | 158.4                       | 2.3 | 159.5                       | 2.4 |
| Qinghu@31         | 1298       | 727         | 0.56         | 0.03               | 0.1717                                | 1.65   | 0.0252                                | 1.55   | 0.0494                                 | 0.56   | 160.9                       | 2.5 | 160.6                       | 2.5 |
| Qinghu@32         | 1906       | 1138        | 0.60         | 0.01               | 0.1711                                | 1.60   | 0.0252                                | 1.53   | 0.0493                                 | 0.46   | 160.4                       | 2.4 | 160.1                       | 2.4 |
| Qinghu@33         | 1930       | 985         | 0.51         | 0.02               | 0.1702                                | 1.57   | 0.0252                                | 1.51   | 0.0490                                 | 0.42   | 159.6                       | 2.3 | 160.4                       | 2.4 |
| Qinghu@34         | 1802       | 877         | 0.49         | 0.02               | 0.1675                                | 1.56   | 0.0246                                | 1.50   | 0.0493                                 | 0.42   | 157.2                       | 2.3 | 156.9                       | 2.3 |

**Table S7.** Oxygen isotope results for the Qinghu zircon standard measured by SIMS.

| <b>Sample</b> | <b>Intensity O<sup>16</sup></b> | <b>O<sup>16</sup>/O<sup>18</sup> Mean</b> | <b>δ<sup>18</sup>O</b> | <b>2SE</b> |
|---------------|---------------------------------|---|------------------------|------------|
| Qinghu@1      | 5.096E+9                        | 2.022E-3                                  | 5.64                   | 0.10       |
| Qinghu@2      | 5.018E+9                        | 2.022E-3                                  | 5.61                   | 0.10       |
| Qinghu@3      | 5.004E+9                        | 2.021E-3                                  | 5.37                   | 0.15       |
| Qinghu@4      | 4.997E+9                        | 2.021E-3                                  | 5.34                   | 0.13       |
| Qinghu@5      | 4.976E+9                        | 2.021E-3                                  | 5.55                   | 0.08       |
| Qinghu@6      | 4.958E+9                        | 2.021E-3                                  | 5.36                   | 0.28       |
| Qinghu@7      | 4.937E+9                        | 2.022E-3                                  | 5.69                   | 0.41       |
| Qinghu@9      | 4.616E+9                        | 2.030E-3                                  | 5.81                   | 0.14       |
| Qinghu@8      | 4.743E+9                        | 2.029E-3                                  | 5.25                   | 0.15       |
| Qinghu@7      | 4.813E+9                        | 2.028E-3                                  | 5.74                   | 0.11       |
| Qinghu@6      | 4.813E+9                        | 2.027E-3                                  | 5.51                   | 0.13       |
| Qinghu@5      | 4.889E+9                        | 2.027E-3                                  | 5.33                   | 0.10       |
| Qinghu@4      | 4.848E+9                        | 2.027E-3                                  | 5.51                   | 0.13       |
| Qinghu@3      | 4.887E+9                        | 2.027E-3                                  | 5.25                   | 0.09       |
| Qinghu@2      | 4.878E+9                        | 2.026E-3                                  | 4.98                   | 0.11       |
| Qinghu@10     | 4.611E+9                        | 2.031E-3                                  | 5.92                   | 0.10       |
| Qinghu@1      | 4.971E+9                        | 2.026E-3                                  | 5.37                   | 0.22       |
| Qinghu@1      | 1.638E+9                        | 2.025E-3                                  | 5.53                   | 0.23       |
| Qinghu@2      | 1.628E+9                        | 2.025E-3                                  | 5.66                   | 0.19       |
| Qinghu@3      | 1.638E+9                        | 2.025E-3                                  | 5.77                   | 0.29       |
| Qinghu@4      | 1.629E+9                        | 2.025E-3                                  | 5.54                   | 0.29       |
| Qinghu@5      | 1.639E+9                        | 2.024E-3                                  | 5.36                   | 0.30       |
| Qinghu@6      | 1.640E+9                        | 2.025E-3                                  | 5.88                   | 0.22       |
| Qinghu@7      | 1.632E+9                        | 2.025E-3                                  | 5.59                   | 0.22       |
| Qinghu@8      | 1.620E+9                        | 2.025E-3                                  | 5.59                   | 0.15       |
| Qinghu@9      | 1.614E+9                        | 2.024E-3                                  | 5.47                   | 0.21       |
| Qinghu@10     | 1.608E+9                        | 2.025E-3                                  | 5.74                   | 0.24       |
| Qinghu@11     | 1.609E+9                        | 2.024E-3                                  | 5.50                   | 0.21       |
| Qinghu@13     | 1.615E+9                        | 2.024E-3                                  | 5.46                   | 0.32       |
| Qinghu@14     | 1.610E+9                        | 2.024E-3                                  | 5.51                   | 0.23       |
| Qinghu@15     | 1.619E+9                        | 2.025E-3                                  | 5.54                   | 0.26       |
| Qinghu@16     | 1.613E+9                        | 2.024E-3                                  | 5.51                   | 0.27       |
| Qinghu@17     | 1.610E+9                        | 2.025E-3                                  | 5.68                   | 0.17       |
| Qinghu@18     | 1.611E+9                        | 2.024E-3                                  | 5.21                   | 0.20       |
| Qinghu@19     | 1.606E+9                        | 2.024E-3                                  | 5.66                   | 0.34       |
| Qinghu@20     | 1.602E+9                        | 2.024E-3                                  | 5.63                   | 0.26       |
| Qinghu@21     | 1.596E+9                        | 2.024E-3                                  | 5.50                   | 0.18       |
| Qinghu@22     | 1.591E+9                        | 2.023E-3                                  | 5.30                   | 0.24       |
| Qinghu@23     | 1.586E+9                        | 2.024E-3                                  | 5.59                   | 0.27       |

**Table S8.** Lu-Hf-Yb isotope data for the reference zircons measured by LA-MC-ICP-MS.

|                        | $^{177}\text{Hf}$ | $^{180}\text{Hf}$ | $^{176}\text{Yb}/^{177}\text{Hf}$ | 2SE      | $^{176}\text{Lu}/^{177}\text{Hf}$ | 2SE      | $^{176}\text{Hf}/^{177}\text{Hf}$ | 2SE      |
|------------------------|-------------------|-------------------|-----------------------------------|----------|-----------------------------------|----------|-----------------------------------|----------|
| <b>91500</b>           |                   |                   |                                   |          |                                   |          |                                   |          |
| 91500-1                | 1.627664          | 3.144839          | 0.008422                          | 0.000014 | 0.000341                          | 0.000000 | 0.282286                          | 0.000018 |
| 91500-10               | 1.652320          | 3.188722          | 0.008146                          | 0.000013 | 0.000333                          | 0.000000 | 0.282320                          | 0.000020 |
| 91500-11               | 1.629503          | 3.143976          | 0.006268                          | 0.000006 | 0.000260                          | 0.000000 | 0.282293                          | 0.000020 |
| 91500-12               | 1.657093          | 3.197171          | 0.007463                          | 0.000006 | 0.000305                          | 0.000000 | 0.282276                          | 0.000018 |
| 91500-13               | 1.664010          | 3.210257          | 0.007363                          | 0.000006 | 0.000301                          | 0.000000 | 0.282284                          | 0.000018 |
| 91500-14               | 1.625557          | 3.136035          | 0.005351                          | 0.000074 | 0.000224                          | 0.000003 | 0.282258                          | 0.000017 |
| 91500-15               | 1.560640          | 3.010937          | 0.007211                          | 0.000028 | 0.000295                          | 0.000001 | 0.282301                          | 0.000020 |
| 91500-16               | 1.569996          | 3.028963          | 0.006862                          | 0.000033 | 0.000282                          | 0.000001 | 0.282288                          | 0.000019 |
| 91500-17               | 1.595404          | 3.079235          | 0.007453                          | 0.000007 | 0.000302                          | 0.000000 | 0.282283                          | 0.000017 |
| 91500-18               | 1.590446          | 3.069824          | 0.007440                          | 0.000008 | 0.000301                          | 0.000000 | 0.282283                          | 0.000020 |
| 91500-19               | 1.579769          | 3.048773          | 0.007456                          | 0.000008 | 0.000302                          | 0.000000 | 0.282317                          | 0.000019 |
| 91500-2                | 1.686070          | 3.257064          | 0.006447                          | 0.000093 | 0.000265                          | 0.000004 | 0.282293                          | 0.000016 |
| 91500-20               | 1.566737          | 3.023602          | 0.007429                          | 0.000007 | 0.000301                          | 0.000000 | 0.282285                          | 0.000019 |
| 91500-21               | 1.597771          | 3.083330          | 0.007433                          | 0.000008 | 0.000301                          | 0.000000 | 0.282291                          | 0.000019 |
| 91500-22               | 1.592417          | 3.073255          | 0.007517                          | 0.000009 | 0.000305                          | 0.000000 | 0.282277                          | 0.000020 |
| 91500-23               | 1.561962          | 3.014222          | 0.007408                          | 0.000007 | 0.000301                          | 0.000000 | 0.282283                          | 0.000016 |
| 91500-24               | 1.568335          | 3.026431          | 0.007284                          | 0.000007 | 0.000296                          | 0.000000 | 0.282284                          | 0.000017 |
| 91500-25               | 1.549805          | 2.990782          | 0.007475                          | 0.000006 | 0.000303                          | 0.000000 | 0.282291                          | 0.000020 |
| 91500-26               | 1.572935          | 3.035692          | 0.007339                          | 0.000007 | 0.000298                          | 0.000000 | 0.282281                          | 0.000018 |
| 91500-27               | 1.584588          | 3.057900          | 0.007537                          | 0.000009 | 0.000306                          | 0.000000 | 0.282296                          | 0.000018 |
| 91500-28               | 1.568369          | 3.026822          | 0.007358                          | 0.000007 | 0.000299                          | 0.000000 | 0.282289                          | 0.000016 |
| 91500-29               | 1.565291          | 3.020802          | 0.007460                          | 0.000007 | 0.000303                          | 0.000000 | 0.282281                          | 0.000019 |
| 91500-3                | 1.695464          | 3.274521          | 0.007337                          | 0.000024 | 0.000299                          | 0.000001 | 0.282277                          | 0.000019 |
| 91500-30               | 1.575651          | 3.040857          | 0.007387                          | 0.000008 | 0.000300                          | 0.000000 | 0.282320                          | 0.000019 |
| 91500-31               | 1.572345          | 3.034601          | 0.007426                          | 0.000008 | 0.000302                          | 0.000000 | 0.282305                          | 0.000018 |
| 91500-4                | 1.666023          | 3.217405          | 0.005999                          | 0.000007 | 0.000250                          | 0.000000 | 0.282278                          | 0.000017 |
| 91500-5                | 1.649072          | 3.184230          | 0.008417                          | 0.000007 | 0.000342                          | 0.000000 | 0.282301                          | 0.000019 |
| 91500-6                | 1.702435          | 3.286272          | 0.007492                          | 0.000006 | 0.000305                          | 0.000000 | 0.282313                          | 0.000018 |
| 91500-7                | 1.664552          | 3.213144          | 0.007437                          | 0.000006 | 0.000303                          | 0.000000 | 0.282285                          | 0.000018 |
| 91500-8                | 1.644401          | 3.173756          | 0.007424                          | 0.000007 | 0.000302                          | 0.000000 | 0.282291                          | 0.000017 |
| 91500-9                | 1.645675          | 3.176084          | 0.007426                          | 0.000006 | 0.000303                          | 0.000000 | 0.282302                          | 0.000017 |
| <b>Mud Tank zircon</b> |                   |                   |                                   |          |                                   |          |                                   |          |
| mt-1.xls               | 2.651471          | 5.123306          | 0.000632                          | 0.000004 | 0.000022                          | 0.000000 | 0.282480                          | 0.000013 |
| mt-10.xls              | 2.616690          | 5.049641          | 0.001496                          | 0.000016 | 0.000052                          | 0.000001 | 0.282508                          | 0.000013 |
| mt-11.xls              | 2.538534          | 4.897644          | 0.002078                          | 0.000004 | 0.000071                          | 0.000000 | 0.282496                          | 0.000013 |
| mt-12.xls              | 2.637911          | 5.089402          | 0.000503                          | 0.000003 | 0.000018                          | 0.000000 | 0.282499                          | 0.000014 |
| mt-13.xls              | 2.490606          | 4.804903          | 0.001405                          | 0.000016 | 0.000049                          | 0.000001 | 0.282506                          | 0.000014 |
| mt-14.xls              | 2.646944          | 5.106372          | 0.000433                          | 0.000004 | 0.000015                          | 0.000000 | 0.282498                          | 0.000014 |
| mt-15.xls              | 2.452983          | 4.732356          | 0.002010                          | 0.000010 | 0.000069                          | 0.000000 | 0.282497                          | 0.000014 |
| mt-16.xls              | 2.564885          | 4.948345          | 0.000484                          | 0.000004 | 0.000018                          | 0.000000 | 0.282509                          | 0.000014 |

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|           |          |          |          |          |          |          |          |          |
|-----------|----------|----------|----------|----------|----------|----------|----------|----------|
| mt-17.xls | 2.697175 | 5.206067 | 0.000522 | 0.000003 | 0.000019 | 0.000000 | 0.282490 | 0.000013 |
| mt-18.xls | 2.692783 | 5.197244 | 0.000387 | 0.000009 | 0.000014 | 0.000000 | 0.282479 | 0.000012 |
| mt-19.xls | 2.724642 | 5.258769 | 0.000276 | 0.000006 | 0.000010 | 0.000000 | 0.282488 | 0.000013 |
| mt-2.xls  | 2.571912 | 4.968119 | 0.002080 | 0.000004 | 0.000071 | 0.000000 | 0.282480 | 0.000012 |
| mt-20.xls | 2.634224 | 5.083795 | 0.000513 | 0.000003 | 0.000018 | 0.000000 | 0.282485 | 0.000015 |
| mt-21.xls | 2.710322 | 5.230677 | 0.000258 | 0.000003 | 0.000009 | 0.000000 | 0.282478 | 0.000013 |
| mt-22.xls | 2.543316 | 4.908427 | 0.000772 | 0.000003 | 0.000028 | 0.000000 | 0.282477 | 0.000014 |
| mt-23.xls | 2.539606 | 4.900889 | 0.000762 | 0.000004 | 0.000028 | 0.000000 | 0.282478 | 0.000014 |
| mt-24.xls | 2.577200 | 4.973524 | 0.000716 | 0.000005 | 0.000026 | 0.000000 | 0.282492 | 0.000014 |
| mt-25.xls | 2.683558 | 5.178781 | 0.000276 | 0.000003 | 0.000010 | 0.000000 | 0.282491 | 0.000014 |
| mt-26.xls | 2.549446 | 4.920114 | 0.000773 | 0.000005 | 0.000028 | 0.000000 | 0.282492 | 0.000013 |
| mt-27.xls | 2.577465 | 4.973948 | 0.001855 | 0.000013 | 0.000064 | 0.000000 | 0.282479 | 0.000014 |
| mt-28.xls | 2.607490 | 5.032076 | 0.000431 | 0.000011 | 0.000016 | 0.000000 | 0.282485 | 0.000012 |
| mt-29.xls | 2.447394 | 4.722758 | 0.000694 | 0.000003 | 0.000025 | 0.000000 | 0.282486 | 0.000014 |
| mt-3.xls  | 2.725962 | 5.264711 | 0.000579 | 0.000006 | 0.000021 | 0.000000 | 0.282479 | 0.000013 |
| mt-30.xls | 2.625273 | 5.066452 | 0.000465 | 0.000004 | 0.000017 | 0.000000 | 0.282485 | 0.000011 |
| mt-31.xls | 2.523341 | 4.869706 | 0.000625 | 0.000003 | 0.000023 | 0.000000 | 0.282490 | 0.000013 |
| mt-4.xls  | 2.752866 | 5.316508 | 0.000423 | 0.000004 | 0.000015 | 0.000000 | 0.282494 | 0.000012 |
| mt-5.xls  | 2.753541 | 5.317002 | 0.000267 | 0.000003 | 0.000010 | 0.000000 | 0.282477 | 0.000012 |
| mt-6.xls  | 2.727296 | 5.264702 | 0.000253 | 0.000003 | 0.000009 | 0.000000 | 0.282483 | 0.000012 |
| mt-7.xls  | 2.753695 | 5.315736 | 0.000371 | 0.000004 | 0.000013 | 0.000000 | 0.282486 | 0.000013 |
| mt-8.xls  | 2.619977 | 5.057033 | 0.000770 | 0.000004 | 0.000028 | 0.000000 | 0.282492 | 0.000014 |
| mt-9.xls  | 2.601437 | 5.020727 | 0.000764 | 0.000003 | 0.000028 | 0.000000 | 0.282479 | 0.000013 |

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## References:

- Bas, M. J., Maitre, R. W., Streckeisen, A., Zanettin, B., 1986. A Chemical classification of volcanic rocks based on the Total Alkali-Silica Diagram. *J. Petrol.* 27, 745–750. <https://doi.org/10.1093/petrology/27.3.745>.
- Bell, E. A., Harrison, T. M., 2013. Post-Hadean transitions in Jack Hills zircon provenance: A signal of the Late Heavy Bombardment?. *Earth Planet. Sci. Lett.* 364, 1–11, <https://10.1016/j.epsl.2013.01.001>.
- Boehnke, P., Barboni, M., Bell, E., 2016. Zircon U/Th model ages in the presence of melt heterogeneity. *Quat. Geochronol.* 34, 69–74. <https://10.1016/j.quageo.2016.03.005>.
- Chen, Z., Zeng, Z., Yin, X., Wang, X., Zhang, Y., Chen, S., Shu, Y., Guo, K., Li, X., 2019. Petrogenesis of highly fractionated rhyolites in the southwestern Okinawa Trough: Constraints from whole-rock geochemistry data and Sr-Nd-Pb-O isotopes. *Geol. J.* 54, 316–332, <https://10.1002/gj.3179>.
- Faghihi, V., Meijer, H. A. J., Gröning, M., 2015. A thoroughly validated spreadsheet for calculating isotopic abundances ( $^2\text{H}$ ,  $^{17}\text{O}$ ,  $^{18}\text{O}$ ) for mixtures of waters with different isotopic compositions. *Rapid Commun. Mass Spectrom.* 29, 1351–1356. <https://DOI:10.1002/rcm.7232>.
- Ferry, J., Watson, E., 2007. New thermodynamic models and revised calibrations for the Ti-in-zircon and Zr-in-rutile thermometers. *Contrib. Mineral. Petrol.* 154, 429–437. <https://10.1007/s00410-007-0201-0>.

- Griffin, W., Pearson, N J., Belousova, E., Jackson, SE v., Van Achterbergh, E, O'Reilly, Suzanne Y, Shee, S R., 2000. The Hf isotope composition of cratonic mantle: LAM-MC-ICPMS analysis of zircon megacrysts in kimberlites. *Geochim. Cosmochim. Acta* 64, 133–147. [https://10.1016/S0016-7037\(99\)00343-9](https://10.1016/S0016-7037(99)00343-9).
- Li, Q. L., Li, Xian-Hua, Liu, Y., Tang, G. Q., Yang, J. H., Zhu, W. G., 2010a. Precise U-Pb and Pb–Pb dating of Phanerozoic baddeleyite by SIMS with oxygen flooding technique. *J. Anal. At. Spectrom.* 25, 1107–1113. <https://10.1039/B923444F>.
- Li, X., Tang, G., Gong, B., Yang, Y., Hou, K., Hu, Z., Li, Q., Liu, Y., Li, W., 2013. Qinghu zircon: A working reference for microbeam analysis of U-Pb age and Hf and O isotopes. *Chin. Sci. Bull.* 58, 4647–4654. <https://10.1007/s11434-013-5932-x>.
- Li, X. H., Liu, Y., Li, Q. L., Guo, C. H., Chamberlain, K. R., 2009. Precise determination of Phanerozoic zircon Pb/Pb age by multicollector SIMS without external standardization. *Geochem. Geophys. Geosyst.* 10, Q04010. <https://doi.org/10.1029/2009GC002400>.
- 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., 2010b. Penglai zircon megacrysts: a potential new working reference material for microbeam determination of Hf–O isotopes and U-Pb age. *Geostand. Geoanal. Res.* 34, 117–134. <https://doi.org/10.1111/j.1751-908X.2010.00036.x>.
- Li, Z., Chu, F., Zhu, J., Ding, Y., Zhu, Z., Liu, J., Wang, H., Li, X., Dong, Y., Zhao, D., 2019. Magmatic sulfide formation and oxidative dissolution in the SW Okinawa Trough: A precursor to metal-bearing magmatic fluid. *Geochim. Cosmochim. Acta* 258, 138–155. <https://10.1016/j.gca.2019.05.024>.

- Liu, Y., Li, X. H., Li, Q. L., Tang, G. Q., Yin, Q. Z., 2011. Precise U-Pb zircon dating at a scale of <5 micron by the CAMECA 1280 SIMS using a Gaussian illumination probe. *J. Anal. At. Spectrom.* 26, 845. [10.1039/C0JA00113A](https://doi.org/10.1039/C0JA00113A), [https:// 10.1039/C0JA00113A](https://doi.org/10.1039/C0JA00113A).
- Ludwig, K., 2001. Users Manual for Isoplot/Ex rev. 2.49. Berkeley Geochronology Center, Berkeley. CA, Special Publications, 1a, 1, p. 56.
- McDonough, W. F., Sun, S. S., 1995. The composition of the Earth. *Chem. Geol.* 120, 223–253. [https://doi.org/10.1016/0009-2541\(94\)00140-4](https://doi.org/10.1016/0009-2541(94)00140-4).
- Roberts, M. P., Clemens, J. D., 1993. Origin of high-potassium, calc-alkaline, I-type granitoids. *Geology* 21, 825–828. [https://doi.org/10.1130/0091-7613\(1993\)021<0825:OOHPTA>2.3.CO;2](https://doi.org/10.1130/0091-7613(1993)021<0825:OOHPTA>2.3.CO;2).
- Schmitt, A. K., Stockli, D. F., Hausback, B. P., 2006. Eruption and magma crystallization ages of Las Tres Vírgenes (Baja California) constrained by combined  $^{230}\text{Th}/^{238}\text{U}$  and (U–Th)/He dating of zircon. *J. Volcanol. Geotherm. Res.* 158, 281–295. <http://10.1016/j.jvolgeores.2006.07.005>.
- Sláma, J., Košler, J., Condon, D. J., Crowley, J. L., Gerdes, A., Hanchar, J. M., Horstwood, M. S., Morris, G. A., Nasdala, L., Norberg, N., 2008. Plešovice zircon—a new natural reference material for U-Pb and Hf isotopic microanalysis. *Chem. Geol.* 249, 1–35. <http://dx.doi.org/10.1016/j.chemgeo.2007.11.005>.
- Stacey, J. t., Kramers, J., 1975. Approximation of terrestrial lead isotope evolution by a two-stage model. *Earth Planet. Sci. Lett.* 26, 207–221. [https://10.1016/0012-821X\(75\)90088-6](https://doi.org/10.1016/0012-821X(75)90088-6).

Tang, G. Q., Li, X. H., Li, Q. L., Liu, Y., Ling, X. X., Yin, Q. Z., 2015. Deciphering the physical mechanism of the topography effect for oxygen isotope measurements using a Cameca IMS-1280 SIMS. *J. Anal. At. Spectrom.* 30, 950–956. [https://10.1039/C4JA00458B](https://doi.org/10.1039/C4JA00458B).

Wiedenbeck, M., Alle, P., Corfu, F., Griffin, W., Meier, M., Oberli, F. v., Quadt, A. v., Roddick, J., Spiegel, W., 1995. Three natural zircon standards for U-Th-Pb, Lu-Hf, trace element and REE analyses. *Geostandards newsletter* 19, 1–23, <https://doi.org/10.1111/j.1751-908X.1995.tb00147.x>.

Woodhead, J., Hergt, J., Shelley, M., Eggins, S., Kemp, R., 2004. Zircon Hf-isotope analysis with an excimer laser, depth profiling, ablation of complex geometries, and concomitant age estimation. *Chem. Geol.* 209, 121–135. <https://doi.org/10.1016/j.chemgeo.2004.04.026>.

Woodhead, J. D., Hergt, J. M., 2005. A preliminary appraisal of seven natural zircon reference materials for in situ Hf isotope determination. *Geostand. Geoanal. Res.* 29, 183–195. <https://doi.org/10.1111/j.1751-908X.2005.tb00891.x>.

Yuan, H., Gao, S., Liu, X., Li, H. M., Günther, D., Wu, F., 2007. Accurate U-Pb age and trace element determinations of zircon by laser ablation inductively coupled plasma mass spectrometry. *Geostand. Geoanal. Res.* 28, 353–370. [https://10.1111/j.1751-908X.2004.tb00755.x](https://doi.org/10.1111/j.1751-908X.2004.tb00755.x).