Zircon U-Pb Age Determination of Volcanic Eruptions in Lutao and Lanyu in the Northern Luzon Magmatic Arc

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ABSTRACT

This paper reports for the first time zircon U-Pb ages of volcanic rocks and sands from Lutao and Lanyu, two islets off SE Taiwan in the north Luzon arc. The samples include (1) seven andesites from four volcanic units and three river/beach sands from Lutao and (2) five basaltic andesites from four volcanic units and two river/beach sands from Lanyu. The Lutao andesites contain abundant magmatic zircons, aging from ~1.54 to ~1.24 Ma for individual sample, which yielded an overall mean $^{206}\text{Pb}/^{238}\text{U}$ age of $1.31 \pm 0.03$ Ma ($n = 190$, MSWD = 2.6). This is slightly older than, or broadly coincident with, a mean $^{206}\text{Pb}/^{238}\text{U}$ age of $1.23 \pm 0.03$ Ma ($n = 103$, MSWD = 1.9) given by detrital zircons from the three sands. The Lanyu volcanics appear to have less abundant magmatic zircons, aging from ~2.72 to ~2.35 Ma for individual sample, which yielded an overall mean $^{206}\text{Pb}/^{238}\text{U}$ age of $2.61 \pm 0.13$ Ma ($n = 11$, MSWD = 1.8). This accords with a mean $^{206}\text{Pb}/^{238}\text{U}$ age of $2.69 \pm 0.11$ Ma ($n = 34$, MSWD = 4.7) obtained by detrital zircons from the two sands. The age data suggest that in Lutao and Lanyu the major volcanic eruptions occurred at ~1.3 and ~2.6 Ma, respectively. Moreover, volcanic samples from both islets contain various amounts of older inherited zircons, ~11% in Lutao and up to ~82% in Lanyu, which together with detrital zircons from the sands show main age peaks at ~150 Ma and ~1.9 and ~2.5 Ga, consistent with the notion for a “hidden” continental crust involved in the genesis of the northern Luzon magmatic arc.

Key words: Zircon U-Pb age, Volcanic eruption, Lutao, Lanyu, Luzon arc

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1. INTRODUCTION

Taiwan is an active orogen resulting from collision between the southeastern margin of the Eurasian continent and the northern Luzon arc sitting on the western Philippine Sea plate, which started ca. 5 Ma (Teng 1990). In eastern Taiwan, the Coastal Range and two offshore islets, Lutao and Lanyu, are the major components of the northern Luzon arc which was formed in an intra-oceanic setting by the eastward subduction of the South China Sea plate beneath the western Philippine Sea plate (Fig. 1). Ages of the northern Luzon arc magmatism, however, remain poorly constrained. For example, regarding the eruptions in Lutao and Lanyu, several radiogenic isotope dating methods have yielded age results of significant variations or even discrepancies. In this paper, we report for the first time in-situ zircon U-Pb ages from Lutao and Lanyu that enable us to better delineate not only the magmatic durations specifically as well the petrogenesis over the northern Luzon arc system in general.

2. BACKGROUND AND SAMPLES

The volcanic rocks of Lutao (Fig. 1a) and Lanyu (Fig. 1b) are composed generally of pyroclastic agglomerates, volcanic breccias, lava flows and dykes (Chen et al. 1994a, b). In Lanyu, ophiolitic fragments are distributed sparsely and regarded as the oldest rock unit (Fig. 1b), along with some limestone boulders that contain Miocene foraminifera, bryozoa, and calcareous algae (Ho 1975). The volcanic ages of the two islets have been studied using various radiogenic isotope dating methods, yielding (1) K-Ar ages of 4.3 - 1.8 and 25.1 - 3.7 Ma from Lutao and Lanyu, respectively (Richard et al. 1986), (2) Ar-Ar ages of 1.5 - 1.4 and 6.6 - 3.5 Ma, respectively (Lo et al. 1994), (3) zircon fission-track ages of 1.7 - 0.5 and 3.3 - 1.4 Ma, respectively.

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(Yang et al. 1995), and (4) Rb-Sr mineral isochron ages of 9.4 - 1.1 Ma from Lutao (Lan et al. 1986).

2.1 Lutao

The volcanic sequences are subdivided into four units, which are, from bottom to top, the Ameishan volcanic breccia, the Niutzushan andesite, the Kungkuan andesite and the Huoshashan andesite (Fig. 1a). Overlying marine terrace deposits, termed the Hsuwenchuan formation, are mainly Late Pleistocene-Holocene coral reefs and red soils with reef limestone fragments (Chen et al. 1994a). In this study, we collected samples from various localities (Fig. 1a) including seven andesitic rocks from the four volcanic units (LTA-01 to LTA-07) and three sands from beaches or river mouths (LTS-01 to LTS-03). The GPS coordinates are listed in Table 1 and field photographs of each sample site are shown in Fig. 2.

2.2 Lanyu

The volcanic sequences are also subdivided into four units, i.e., from bottom to top, the Lungtouyen volcanic breccia, the Tungching andesite, the Mantoushan andesite and the Shuangshihyen volcanic breccia (Fig. 1b). The cover rocks are Late Pleistocene-Holocene marine terrace deposits, termed the Szutaokou formation, composed mainly of raised coral reefs and small-scaled alluvial fan (Chen et al. 1994b). We collected five samples of basalt to basaltic andesite composition from the four volcanic units (LYA-01 to LYA-05), along with river sand (LYS-01) and beach sand (LYS-02), from the islet (Fig. 1b). Their GPS coordinates are also listed in Table 1 and field photographs are shown in Fig. 3.

3. ANALYTICAL METHODS

Zircons were separated from ~2 - 3 kg samples using
Table 1. Summary of zircon U-Pb ages and relevant information of samples from Lutao and Lanyu.

| Sample | Longitude | Latitude | Volcanic Unit | Occurrence | Rock Type | SiO$_2$ (wt.%)* | Age ± 2σ (Ma) | Remarks |
|--------|-----------|----------|---------------|------------|-----------|----------------|---------------|---------|
| **Lutao** | | | | | | | | |
| LTA-01 | E 121°28'24.6'' | N 22°38'51.1'' | Huoshaoshan andesite | pyroclastics | andesite | 56.70 | 1.24 ± 0.08 | |
| LTA-02 | E 121°29'15.3'' | N 22°38'37.9'' | Ameishan volcanic breccia | pyroclastics | basaltic andesite | 55.33 | 1.44 ± 0.06 | |
| LTA-03 | E 121°30'04.2'' | N 22°38'39.5'' | Ameishan volcanic breccia | pyroclastics | basaltic andesite | 52.45 | 1.54 ± 0.12 | |
| LTA-04 | E 121°29'43.1'' | N 23°40'32.7'' | Kungkuan andesite | lava flow | andesite | 60.55 | 1.25 ± 0.05 | |
| LTA-05 | E 121°30'22.4'' | N 22°39'34.3'' | Kungkuan andesite | lava flow | basaltic andesite | 53.12 | 1.36 ± 0.05 | |
| LTA-06 | E 121°30'22.4'' | N 22°39'21.7'' | Kungkuan andesite | lava flow | andesite | 60.78 | 1.24 ± 0.04 | |
| LTA-07 | E 121°29'12.7'' | N 22°40'35.5'' | Niuztshan volcanic breccia | pyroclastics | basaltic andesite | 55.74 | 1.28 ± 0.06 | |
| LTS-01 | E 121°28'51.9'' | N 22°38'46.5'' | beach sand | — | — | — | — | |
| LTS-02 | E 121°29'14.1'' | N 22°38'38.5'' | river sand | — | — | — | — | |
| LTS-03 | E 121°30'22.3'' | N 22°39'32.3'' | river sand | — | — | — | — | |
| **Lanyu** | | | | | | | | |
| LYA-01 | E 121°34'02.8'' | N 22°05'00.5'' | Shuangshihyen volcanic breccia | pyroclastics | basalt | 50.79 | 2.50 ± 0.17 | |
| LYA-02 | E 121°34'07.7'' | N 22°03'49.6'' | Tungching andesite | lava flow | basalt | 49.23 | — | no magmatic zircon obtained |
| LYA-03 | E 121°35'45.9'' | N 22°01'26.2'' | Lungtouyen volcanic breccia | pyroclastics | basalt | 47.34 | 2.35 ± 0.21 | |
| LYA-04 | E 121°31'19.5'' | N 22°02'25.4'' | Mantoushan andesite | lava flow | basaltic andesite | 55.68 | 2.72 ± 0.23 | |
| LYA-05 | E 121°30'05.1'' | N 22°04'46.7'' | Shuangshihyen volcanic breccia | pyroclastics | basaltic andesite | 53.46 | — | no magmatic zircon obtained |
| LYS-01 | E 121°33'52.5'' | N 22°03'27.0'' | river sand | — | — | — | — | |
| LYS-02 | E 121°33'53.2'' | N 22°03'25.8'' | beach sand | — | — | — | — | |

Note: *footnotes: whole-rock SiO$_2$ contents from Shao et al. (unpubl. data).
Fig. 2. Field occurrence photos of the Lutao samples.

Fig. 3. Field occurrence photos of the Lanyu samples.
conventional separation techniques, i.e., heavy-liquid and magnetic methods, then mounted in epoxy and polished to expose the interior of zircon grains. Cathodoluminescence (CL) images were taken and used to check the internal structures of individual zircons and to select positions for analyses (Figs. 4 and 5). In-situ zircon U-Pb isotope dating analyses were performed at the Dr. Shen-su Sun Memorial Lab located at the Department of Geosciences, National Taiwan University, equipped with an Agilent® 7500 s ICP-MS (inductively coupled plasma mass spectrometer) attached to a New Wave UP213 laser ablation system. The laser repetition rate used for all analyses was 4 Hz, and the ablation pit diameter was ~30 μm. The LA-ICPMS operating conditions and detailed analytical techniques have been reported in Chiu et al. (2009).

Measured U-Th-Pb isotope ratios were calculated using the GLITTER 4.4 (GEMOC) software and calibration was performed using the zircon standard GJ-1 aged at 608.5 ± 0.4 Ma (Jackson et al. 2004). The relative standard deviations of reference values for GJ-1 were set at 2%. Two

Fig. 4. Selective cathodoluminescence (CL) and stereoscopic images of zircons from Lutao. Yellow circles denote laser spots, i.e., ~30 μm in diameter, with U-Pb ages (Ma) shown.

Fig. 5. Selective cathodoluminescence (CL) images of zircons from Lanyu. Yellow circles denote laser spots, i.e., ~30 μm in diameter, with U-Pb ages (Ma) shown.
other well-known zircon standards 91500 and Mud Tank, together with a new zircon standard Plešovice (337.1 ± 0.4 Ma; Sláma et al. 2008), were used for data quality control. The common lead was directly corrected using the common lead correction function proposed by Andersen (2002), and the weighted mean U-Pb ages and concordia plots were carried out by Isosplot v. 3.0 (Ludwig 2003). Given that precise measurements of $^{207}\text{Pb}/^{235}\text{U}$ and $^{206}\text{Pb}/^{238}\text{U}$ ratios are feasible usually only for Precambrian zircons, due largely to the fact that $^{235}\text{U}$ now comprises less than 1% of natural U and thus relatively little $^{207}\text{Pb}$ can be produced in the Phanerozoic (cf. Ireland and Williams 2003); $^{206}\text{Pb}/^{238}\text{U}$ ages are taken to indicate the crystallization ages of young zircons in this study. Note that $^{207}\text{Pb}/^{206}\text{Pb}$ ages are used only for inherited or detrital zircons older than 1000 Ma.

To demonstrate the ability of precisely determining the very young ages of zircons (i.e., 1 - 3 Ma) of this study, we present here LA-ICPMS zircon U-Pb age result of a dacite sample from the Quaternary Chilungshan volcano, northern Taiwan (Table 2 and Fig. 6), yielding a mean $^{206}\text{Pb}/^{238}\text{U}$ age of 1.11 ± 0.05 Ma (n = 19, MSWD = 1.1 at 95% confidence level or 2σ analytical uncertainties). This age result corresponds within the analytical errors to two zircon $^{206}\text{Pb}/^{238}\text{U}$ ages of 1.08 ± 0.02 and 1.17 ± 0.02 Ma reported also for the Chilungshan dacites using a secondary ion microprobe CAMBEA 1280 (Gao et al. 2010) and a zircon $^{206}\text{Pb}/^{238}\text{U}$ age of 1.04 ± 0.06 Ma obtained from another Chilungshan dacite using the SHRIMP method (Wan et al. 2012).

### 4. RESULTS

Abundant zircons were separated from the Lutao volcanic rocks and sands, except for sample LTA-03 which is a basaltic andesite thus containing less abundant magmatic zircons. Other volcanic samples are of andesitic composition (Table 1). The zircon grains are mostly euhedral and prismatic in shape and light pink in color. They are generally ~150 to 250 μm long and display internal textures of oscillatory or sector zoning in CL and BSE images (Fig. 4). By contrast, zircons are much less abundant from the Lanyu volcanic rocks and sands. This is because the Lanyu volcanics are more mafic, typically from basalt to basaltic andesite composition (Chen et al. 1994b), such as the samples collected by this study (Table 1). Most zircon grains are subhedral to anhedral, generally ~50 to 200 μm long and lacking oscillatory or sector zoning (Fig. 5), despite they have high U concentrations and high Th/U ratios as typical igneous zircons (see below).

#### 4.1 Lutao

Zircon separates were successfully obtained from all seven volcanic rock samples, from the four volcanic units of the islet, and from the three sand samples. The zircon...
### Table 2. (Continued)

| Spot    | U (ppm) | Th/U | $^{207}$Pb/$^{235}$U ± 1 s | $^{206}$Pb/$^{238}$U ± 1 s | $^{207}$Pb/$^{206}$Pb ± 1 s | $^{208}$Pb/$^{232}$Th ± 1 s | Ages (Ma) |
|---------|---------|------|--------------------------|--------------------------|---------------------------|-----------------------------|------------|
| TDC-12  | 835     | 0.556| 0.00044                  | 0.00010                  | 0.00016                   | 0.001273                   | 0.02273    |
| TDC-13  | 469     | 0.292| 0.00003                  | 0.00001                  | 0.00001                   | 0.01654                    | 0.04913    |
| TDC-14  | 660     | 0.426| 0.00184                  | 0.00075                  | 0.00017                   | 0.07915                    | 0.02815    |
| TDC-15  | 599     | 0.549| 0.00032                  | 0.00086                  | 0.00016                   | 0.04170                    | 0.03665    |
| TDC-16  | 438     | 0.298| 0.00029                  | 0.00014                  | 0.00017                   | 0.01240                    | 0.04381    |
| TDC-17  | 374     | 0.305| 0.00034                  | 0.00028                  | 0.00017                   | 0.14748                    | 0.04576    |
| TDC-19  | 1020    | 0.521| 0.00119                  | 0.00045                  | 0.00017                   | 0.05639                    | 0.01675    |
| TDC-21  | 396     | 0.275| 0.00010                  | 0.00011                  | 0.00015                   | 0.04836                    | 0.05080    |
| TDC-22  | 797     | 0.667| 0.00015                  | 0.00055                  | 0.00015                   | 0.07729                    | 0.02221    |

Mean $^{206}$Pb/$^{238}$U age = 1.11 ± 0.05 Ma (N = 19, MSWD = 1.1)

4.1.1 Ameishan Volcanic Breccia

There are two samples collected from this bottom volcanic unit. These are (1) LTA-02 that yielded a weighted mean $^{206}$Pb/$^{238}$U age of 1.44 ± 0.06 Ma (n = 29; MSWD = 3.2), and (2) LTA-03 that yielded an $^{207}$Pb/$^{206}$Pb age of 1.44 ± 0.06 Ma (N = 19, MSWD = 1.1).
| Spot         | U (ppm) | Th/U | $^{207}\text{Pb}/^{206}\text{U}$ | $^{206}\text{Pb}/^{206}\text{Pb}$ | $^{207}\text{Pb}/^{206}\text{Pb}$ | $^{206}\text{Pb}/^{206}\text{Th}$ | Ages (Ma) |
|--------------|---------|------|---------------------------------|---------------------------------|---------------------------------|---------------------------------|-----------|
| LTA01-01     | 251     | 0.420| 5.12369                         | 0.11530                         | 0.33062                         | 0.00702                         | 0.11241   |
| LTA01-02     | 1719    | 1.667| 0.00233                         | 0.00064                         | 0.00022                         | 0.0001                          | 0.0794    |
| LTA01-03     | 593     | 0.962| 0.00197                         | 0.00134                         | 0.00018                         | 0.0002                          | 0.07928   |
| LTA01-04     | 468     | 1.333| 0.00998                         | 0.00166                         | 0.00015                         | 0.0002                          | 0.04839   |
| LTA01-05     | 896     | 0.709| 0.00129                         | 0.00068                         | 0.00020                         | 0.0002                          | 0.04696   |
| LTA01-06     | 375     | 1.333| 0.00108                         | 0.00284                         | 0.00017                         | 0.0003                          | 0.04674   |
| LTA01-07     | 506     | 0.820| 0.00199                         | 0.00139                         | 0.00014                         | 0.0002                          | 0.10218   |
| LTA01-08     | 406     | 1.205| 0.00078                         | 0.00096                         | 0.00012                         | 0.0001                          | 0.04643   |
| LTA01-09     | 868     | 0.840| 0.00211                         | 0.00100                         | 0.00024                         | 0.0002                          | 0.06346   |
| LTA01-10     | 1305    | 1.724| 0.00150                         | 0.00123                         | 0.00020                         | 0.0002                          | 0.05301   |
| LTA01-11     | 1824    | 1.786| 0.00108                         | 0.00013                         | 0.00017                         | 0.0001                          | 0.04640   |
| LTA01-12     | 429     | 0.971| 0.00361                         | 0.00242                         | 0.00023                         | 0.0003                          | 0.11344   |
| LTA01-13     | 392     | 0.971| 0.00125                         | 0.00238                         | 0.00027                         | 0.0003                          | 0.03317   |
| LTA01-14     | 513     | 0.885| 0.00239                         | 0.00165                         | 0.00019                         | 0.0002                          | 0.09052   |
| LTA01-15     | 1779    | 1.667| 0.00242                         | 0.00059                         | 0.00023                         | 0.0001                          | 0.07710   |
| LTA01-16     | 400     | 0.781| 1.08249                         | 0.02499                         | 0.12062                         | 0.00254                         | 0.06509   |
| LTA01-17     | 1216    | 1.515| 0.00248                         | 0.00118                         | 0.00024                         | 0.0002                          | 0.07516   |
| LTA01-18     | 491     | 1.639| 0.00253                         | 0.00416                         | 0.00023                         | 0.0005                          | 0.07885   |
| LTA01-21     | 427     | 0.893| 0.00056                         | 0.00226                         | 0.00020                         | 0.0003                          | 0.02067   |
| LTA01-22     | 4839    | 0.250| 0.01195                         | 0.00282                         | 0.01702                         | 0.00036                         | 0.05097   |
| LTA01-24     | 317     | 1.587| 0.00626                         | 0.00217                         | 0.00024                         | 0.0003                          | 0.18817   |
| LTA01-25     | 458     | 1.075| 0.00151                         | 0.00115                         | 0.00023                         | 0.0002                          | 0.04677   |
| LTA01-26     | 978     | 2.326| 0.00119                         | 0.00046                         | 0.00019                         | 0.0001                          | 0.04652   |
| LTA01-27     | 539     | 0.685| 0.00018                         | 0.00161                         | 0.00017                         | 0.0002                          | 0.00777   |

Mean $^{206}\text{Pb}/^{206}\text{U}$ age = 1.24 ± 0.08 Ma (N = 29, MSWD = 3.2)
Table 3. (Continued)

| Spot       | U (ppm) | Th/U | \(^{206}\text{Pb}/^{238}\text{U} \pm 1\ s | \(^{206}\text{Pb}/^{238}\text{U} \pm 1\ s | \(^{207}\text{Pb}/^{206}\text{Pb} \pm 1\ s | \(^{207}\text{Pb}/^{235}\text{Th} \pm 1\ s | \(^{208}\text{Pb}/^{206}\text{U} \pm 1\ s | \(^{208}\text{Pb}/^{206}\text{Pb} \pm 1\ s | \(^{208}\text{Pb}/^{232}\text{Th} \pm 1\ s |
|------------|---------|------|----------------|----------------|----------------|----------------|----------------|----------------|----------------|
| LTA01-28   | 895     | 1.639| 0.00132 0.00107 | 0.00018 | 0.00002 0.05250 | 0.03739 | 0.00006 | 0.00001 |
| LTA01-29   | 768     | 1.818| 0.00172 0.00085 | 0.00021 | 0.0001 0.05875 | 0.02654 | 0.00007 | 0.00001 |
| LTA01-30   | 398     | 1.818| 0.00096 0.00190 | 0.00015 | 0.0003 0.04651 | 0.08556 | 0.00006 | 0.00002 |
| LTA01-31   | 598     | 0.885| 0.05132 0.02299 | 0.00808 | 0.00018 0.04607 | 0.00210 | 0.00026 | 0.00012 |
| LTA01-32   | 2817    | 2.174| 0.00250 0.00038 | 0.00020 | 0.00001 0.09263 | 0.01011 | 0.00007 | 0.00001 |
| LTA01-33   | 374     | 1.149| 0.00246 0.00250 | 0.00017 | 0.00003 0.10634 | 0.09001 | 0.00005 | 0.00002 |
| LTA01-34   | 324     | 1.149| 0.00225 0.00209 | 0.00017 | 0.00002 0.09627 | 0.07938 | 0.00007 | 0.00002 |
| LTA01-35   | 1946    | 1.818| 0.00024 0.00036 | 0.00017 | 0.00001 0.00995 | 0.01440 | 0.00006 | 0.00001 |
| LTA01-36   | 613     | 1.190| 0.000197 0.000108 | 0.00018 | 0.00001 0.07769 | 0.03875 | 0.00006 | 0.00001 |
| **Mean \(^{206}\text{Pb}/^{238}\text{U} age = 1.24 \pm 0.08\ Ma (N = 29, MSWD = 3.2)** |

| Spot       | U (ppm) | Th/U | \(^{206}\text{Pb}/^{238}\text{U} \pm 1\ s | \(^{206}\text{Pb}/^{238}\text{U} \pm 1\ s | \(^{207}\text{Pb}/^{206}\text{Pb} \pm 1\ s | \(^{207}\text{Pb}/^{235}\text{Th} \pm 1\ s | \(^{208}\text{Pb}/^{206}\text{U} \pm 1\ s | \(^{208}\text{Pb}/^{206}\text{Pb} \pm 1\ s | \(^{208}\text{Pb}/^{232}\text{Th} \pm 1\ s |
|------------|---------|------|----------------|----------------|----------------|----------------|----------------|----------------|----------------|
| LTA02-01   | 1737    | 0.847| 0.00104 0.00039 | 0.00021 | 0.00001 0.03537 | 0.01177 | 0.00007 | 0.00001 |
| LTA02-04   | 1260    | 0.893| 0.00023 0.00053 | 0.00023 | 0.00001 0.00747 | 0.01692 | 0.00007 | 0.00001 |
| LTA02-05   | 1389    | 0.962| 0.00076 0.00062 | 0.00025 | 0.00001 0.02243 | 0.01750 | 0.00008 | 0.00001 |
| LTA02-06   | 605     | 1.316| 0.00151 0.00141 | 0.00024 | 0.00002 0.04651 | 0.04056 | 0.00009 | 0.00003 |
| LTA02-07   | 446     | 0.752| 0.00098 0.00415 | 0.00023 | 0.00005 0.03110 | 0.12565 | 0.00018 | 0.00005 |
| LTA02-08   | 806     | 1.471| 0.00031 0.00094 | 0.00022 | 0.00001 0.01037 | 0.03102 | 0.00008 | 0.00001 |
| LTA02-09   | 2538    | 1.538| 0.00020 0.00090 | 0.00024 | 0.00001 0.06162 | 0.02487 | 0.00007 | 0.00001 |
| LTA02-10   | 217     | 0.498| 0.00201 0.00280 | 0.00021 | 0.00003 0.06865 | 0.08778 | 0.00006 | 0.00006 |
| LTA02-11   | 2140    | 1.136| 0.00173 0.00047 | 0.00022 | 0.00001 0.05667 | 0.01313 | 0.00009 | 0.00001 |
| LTA02-12   | 758     | 1.639| 0.00849 0.00430 | 0.00024 | 0.00005 0.25970 | 0.08344 | 0.00006 | 0.00003 |
| LTA02-13   | 753     | 0.781| 0.00426 0.00150 | 0.00018 | 0.00002 0.16977 | 0.04358 | 0.00008 | 0.00002 |
| LTA02-14   | 956     | 1.389| 0.00164 0.00099 | 0.00026 | 0.00001 0.04625 | 0.00137 | 0.00013 | 0.00001 |
| LTA02-15   | 759     | 1.087| 0.00029 0.00098 | 0.00024 | 0.00001 0.00880 | 0.02941 | 0.00010 | 0.00001 |
| **Mean \(^{206}\text{Pb}/^{238}\text{U} age = 1.44 \pm 0.06\ Ma (N = 20, MSWD = 1.5)** |

Zircon U-Pb Age from Lutao and Lanyu
Table 3. (Continued)

| Spot  | U (ppm) | Th/U | \(^{206}\text{Pb}/^{238}\text{U} \pm 1 s | \(^{206}\text{Pb}/^{238}\text{U} \pm 1 s | \(^{207}\text{Pb}/^{235}\text{Th} \pm 1 s | \(^{208}\text{Pb}/^{206}\text{Th} \pm 1 s | \(^{208}\text{Pb}/^{235}\text{Th} \pm 1 s |
|-------|---------|------|-------------------------------|-------------------------------|-------------------------------|-------------------------------|-------------------------------|
| LTA02-16 | 817 | 1.613 | 0.00133 | 0.00065 | 0.00020 | 0.00001 | 0.04714 | 0.02159 | 0.00007 | 0.00001 |
| LTA02-17 | 331 | 1.351 | 0.15759 | 0.00498 | 0.02089 | 0.00046 | 0.05473 | 0.00083 | 0.00707 | 0.00022 |
| LTA02-18 | 1320 | 0.405 | 0.00043 | 0.00054 | 0.00023 | 0.00001 | 0.01358 | 0.01652 | 0.00012 | 0.00001 |
| LTA02-19 | 1484 | 0.452 | 0.00072 | 0.00047 | 0.00022 | 0.00001 | 0.02335 | 0.01429 | 0.00008 | 0.00001 |
| LTA02-20 | 461 | 0.629 | 8.71367 | 0.24372 | 0.39489 | 0.00918 | 0.16004 | 0.00198 | 0.11380 | 0.00625 |
| LTA02-21 | 587 | 1.042 | 0.00392 | 0.00120 | 0.00037 | 0.00002 | 0.07689 | 0.01988 | 0.00012 | 0.00001 |
| LTA02-22C | 569 | 1.124 | 0.00265 | 0.00123 | 0.00022 | 0.00002 | 0.08871 | 0.03410 | 0.00010 | 0.00001 |
| LTA02-22R | 1613 | 0.476 | 0.00177 | 0.00043 | 0.00025 | 0.00001 | 0.05233 | 0.01087 | 0.00008 | 0.00001 |
| LTA02-23 | 153 | 0.629 | 6.85454 | 0.18462 | 0.37465 | 0.00790 | 0.13727 | 0.00161 | 0.11422 | 0.00636 |
| LTA02-24 | 4426 | 0.667 | 0.00063 | 0.00017 | 0.00021 | 0.00001 | 0.02240 | 0.00511 | 0.00006 | 0.00001 |
| LTA02-25 | 1625 | 1.220 | 0.00120 | 0.00051 | 0.00019 | 0.00001 | 0.04665 | 0.01836 | 0.00007 | 0.00001 |

Mean \(^{206}\text{Pb}/^{238}\text{U} \text{age} = 1.44 \pm 0.06 \text{Ma (N = 20, MSWD = 1.5)}

| Spot  | U (ppm) | Th/U | \(^{206}\text{Pb}/^{238}\text{U} \pm 1 s | \(^{206}\text{Pb}/^{238}\text{U} \pm 1 s | \(^{207}\text{Pb}/^{235}\text{Th} \pm 1 s | \(^{208}\text{Pb}/^{206}\text{Th} \pm 1 s | \(^{208}\text{Pb}/^{235}\text{Th} \pm 1 s |
|-------|---------|------|-------------------------------|-------------------------------|-------------------------------|-------------------------------|-------------------------------|
| LTA03-01 | 1587 | 0.288 | 5.06478 | 0.14943 | 0.28183 | 0.00606 | 0.13034 | 0.00170 | 0.08012 | 0.00168 |
| LTA03-02 | 12516 | 1.515 | 0.00184 | 0.00027 | 0.00029 | 0.00001 | 0.04654 | 0.00578 | 0.00010 | 0.00001 |
| LTA03-03 | 713 | 0.559 | 5.31954 | 0.11737 | 0.32919 | 0.00692 | 0.11722 | 0.00114 | 0.09802 | 0.00292 |
| LTA03-04 | 446 | 0.787 | 0.00063 | 0.00055 | 0.00023 | 0.00002 | 0.02013 | 0.04796 | 0.00008 | 0.00002 |
| LTA03-05 | 1184 | 1.587 | 0.00025 | 0.00077 | 0.00023 | 0.00001 | 0.08034 | 0.02146 | 0.00008 | 0.00001 |
| LTA03-06 | 810 | 1.563 | 0.00016 | 0.00039 | 0.00026 | 0.00001 | 0.04653 | 0.01021 | 0.00009 | 0.00001 |
| LTA03-07 | 791 | 0.893 | 0.00078 | 0.00374 | 0.00023 | 0.00004 | 0.24206 | 0.08013 | 0.00006 | 0.00005 |
| LTA03-08 | 832 | 0.855 | 6.13619 | 0.14209 | 0.35967 | 0.00775 | 0.12375 | 0.00125 | 0.11065 | 0.00391 |
| LTA03-09 | 1302 | 0.862 | 0.00018 | 0.00010 | 0.00028 | 0.00002 | 0.04622 | 0.00777 | 0.00020 | 0.00002 |
| LTA03-10 | 538 | 0.289 | 5.31718 | 0.11843 | 0.33772 | 0.00706 | 0.11421 | 0.00111 | 0.10462 | 0.00349 |
| LTA03-11 | 619 | 1.075 | 0.000218 | 0.000139 | 0.00034 | 0.00002 | 0.04585 | 0.02683 | 0.00037 | 0.00002 |

Mean \(^{206}\text{Pb}/^{238}\text{U} \text{age} = 1.54 \pm 0.12 \text{Ma (N = 12, MSWD = 2.7)}

LTA02 (Ameishan volk. brecchia)

LTA03 (Ameishan volk. brecchia)
### Table 3. (Continued)

| Spot          | U (ppm) | Th/U | 238Pb/206U     | ± 1 s | 206Pb/238U   | ± 1 s | 207Pb/206Pb | ± 1 s | 208Pb/232Th | ± 1 s | Ages (Ma) |
|---------------|---------|------|----------------|-------|--------------|-------|-------------|-------|-------------|-------|-----------|
| LTA03-04      | 0.654   | 0.00079 | 0.00088  | 0.00019 | 0.0001 | 0.03105 | 0.03312 | 0.00007 | 0.00001  |       |           |
| LTA03-05      | 0.662   | 0.00128 | 0.00030  | 0.00020 | 0.0001 | 0.04638 | 0.01015 | 0.00010 | 0.00003  |       |           |
| LTA03-06      | 1.064   | 0.00257 | 0.00090  | 0.00019 | 0.0001 | 0.09614 | 0.02920 | 0.00006 | 0.00001  |       |           |
| LTA03-07      | 1.176   | 0.00210 | 0.00097  | 0.00019 | 0.0001 | 0.07813 | 0.03244 | 0.00008 | 0.00001  |       |           |
| LTA03-08      | 0.658   | 0.00223 | 0.00075  | 0.00020 | 0.0001 | 0.08277 | 0.02418 | 0.00008 | 0.00001  |       |           |
| LTA03-09      | 0.559   | 0.00135 | 0.00154  | 0.00017 | 0.0002 | 0.05707 | 0.05913 | 0.00007 | 0.00002  |       |           |
| LTA03-10      | 0.427   | 0.00134 | 0.00016  | 0.00021 | 0.0001 | 0.04537 | 0.00360 | 0.00007 | 0.00001  |       |           |
| LTA03-11      | 0.518   | 0.00418 | 0.00302  | 0.00015 | 0.0003 | 0.20830 | 0.11445 | 0.00004 | 0.00005  |       |           |
| LTA03-12      | 1.190   | 0.00115 | 0.00081  | 0.00020 | 0.0001 | 0.04122 | 0.02719 | 0.00010 | 0.00001  |       |           |
| LTA03-13      | 0.641   | 0.00049 | 0.00081  | 0.00021 | 0.0001 | 0.01718 | 0.02767 | 0.00006 | 0.00001  |       |           |
| LTA03-14      | 1.613   | 0.00097 | 0.00040  | 0.00018 | 0.0001 | 0.03806 | 0.01382 | 0.00007 | 0.00001  |       |           |
| LTA03-15      | 0.641   | 0.00117 | 0.00075  | 0.00018 | 0.0002 | 0.04672 | 0.02737 | 0.00007 | 0.00003  |       |           |
| LTA03-16      | 0.709   | 0.00051 | 0.00151  | 0.00021 | 0.0002 | 0.01773 | 0.05098 | 0.00008 | 0.00002  |       |           |
| LTA03-17      | 1.020   | 0.00076 | 0.00074  | 0.00019 | 0.0001 | 0.02899 | 0.02686 | 0.00005 | 0.00001  |       |           |

LTA03 (Ameishan vol. breccia)

LTA04 (Kungkuan andesite)

Mean 206Pb/238U age = 1.54 ± 0.12 Ma (N = 12, MSWD = 2.7)
Table 3. (Continued)

| Spot       | U (ppm) | Th/U | 235Pb/238U ± 1 s | 206Pb/238U ± 1 s | 238Pb/206Pb ± 1 s | 208Pb/238U ± 1 s |
|------------|---------|------|-------------------|-------------------|-------------------|-------------------|
| LTA04-15   | 1105.03 | 0.935| 0.00064 ± 0.00019| 0.00019 ± 0.00017| 0.02381 ± 0.01971| 0.00006 ± 0.00001|
| LTA04-16   | 1112.09 | 0.909| 0.00034 ± 0.00018| 0.00018 ± 0.00012| 0.01400 ± 0.02483| 0.00006 ± 0.00001|
| LTA04-17   | 730.565 | 0.565| 0.00056 ± 0.00020| 0.00020 ± 0.00012| 0.02033 ± 0.05300| 0.00008 ± 0.00002|
| LTA04-18   | 1183.901| 0.901| 0.00074 ± 0.00019| 0.00019 ± 0.00014| 0.02926 ± 0.02030| 0.00005 ± 0.00001|
| LTA04-19   | 797.719 | 0.719| 0.00101 ± 0.00019| 0.00019 ± 0.00013| 0.03781 ± 0.02742| 0.00005 ± 0.00001|
| LTA04-20   | 633.568 | 0.568| 0.00123 ± 0.00022| 0.00022 ± 0.00016| 0.03991 ± 0.04803| 0.00017 ± 0.00002|
| LTA04-21   | 751.667 | 0.667| 0.00180 ± 0.00019| 0.00019 ± 0.00014| 0.06929 ± 0.02794| 0.00004 ± 0.00001|
| LTA04-22   | 870.794 | 0.794| 0.00200 ± 0.00018| 0.00018 ± 0.00013| 0.00799 ± 0.03156| 0.00005 ± 0.00001|
| LTA04-23   | 446.111 | 1.111| 0.00371 ± 0.00026| 0.00026 ± 0.00020| 0.10363 ± 0.03351| 0.00013 ± 0.00001|
| LTA04-24   | 838.578 | 0.578| 0.00012 ± 0.00001| 0.00009 ± 0.00003| 0.03013 ± 0.03899| 0.00007 ± 0.00001|
| LTA04-25   | 2393.200| 2.000| 0.00101 ± 0.00017| 0.00017 ± 0.00016| 0.04190 ± 0.00905| 0.00006 ± 0.00001|
| LTA04-26   | 818.704 | 0.704| 0.00010 ± 0.00016| 0.00016 ± 0.00012| 0.00412 ± 0.03358| 0.00004 ± 0.00001|
| LTA04-27   | 1103.100| 1.100| 0.00010 ± 0.00017| 0.00017 ± 0.00015| 0.00421 ± 0.02798| 0.00006 ± 0.00001|
| LTA04-28   | 636.529 | 0.529| 0.00077 ± 0.00010| 0.00010 ± 0.00011| 0.00312 ± 0.03897| 0.00006 ± 0.00001|
| LTA04-29   | 420.847 | 0.847| 0.00249 ± 0.00018| 0.00018 ± 0.00016| 0.09982 ± 0.05078| 0.00005 ± 0.00001|
| LTA04-30   | 616.621 | 0.621| 0.00052 ± 0.00019| 0.00019 ± 0.00016| 0.01998 ± 0.03748| 0.00007 ± 0.00001|

Mean 206Pb/238U age = 1.25 ± 0.05 Ma (N = 30, MSWD = 1.5)

| Spot       | U (ppm) | Th/U | 238U/206Pb ± 1 s | 206Pb/206Pb ± 1 s | 238U/206Pb ± 1 s | 208U/238U ± 1 s |
|------------|---------|------|------------------|-------------------|------------------|------------------|
| LTA05-01   | 559.763 | 0.763| 0.02012 ± 0.00025| 0.00025 ± 0.00017| 0.06254 ± 0.02950| 0.00010 ± 0.00001|
| LTA05-02   | 2166.256| 2.564| 0.00127 ± 0.00020| 0.00020 ± 0.00012| 0.00454 ± 0.00946| 0.00007 ± 0.00001|
| LTA05-03   | 2156.758| 0.758| 0.00099 ± 0.00019| 0.00019 ± 0.00013| 0.03861 ± 0.00875| 0.00006 ± 0.00001|
| LTA05-04   | 1341.617| 0.617| 0.00255 ± 0.00023| 0.00023 ± 0.00019| 0.08154 ± 0.01639| 0.00011 ± 0.00001|
| LTA05-05   | 537.172 | 1.724| 0.00175 ± 0.00021| 0.00021 ± 0.00015| 0.05988 ± 0.04338| 0.00007 ± 0.00001|
| LTA05-06   | 727.138 | 1.38 | 0.00095 ± 0.00015| 0.00015 ± 0.00012| 0.04636 ± 0.00451| 0.00009 ± 0.00001|

Mean 206Pb/208U age = 1.36 ± 0.05 Ma (N = 38, MSWD = 1.7)
Table 3. (Continued)

| Spot    | U (ppm) | Th/U | 206Pb/238U ± 1 s | 206Pb/238U ± s | 207Pb/206Pb ± 1 s | 207Pb/206Pb ± s | 208Pb/206Pb ± 1 s | 208Pb/206Pb ± s | Ages (Ma) |
|---------|---------|------|-----------------|----------------|-----------------|-----------------|-----------------|-----------------|-----------|
| LTA05-07 | 489     | 1.020 | 0.00122         | 0.00100        | 0.00020         | 0.00001         | 0.04475         | 0.03468        | 1.3       |
| LTA05-08 | 175     | 1.042 | 0.00272         | 0.00471        | 0.00031         | 0.00006         | 0.06400         | 0.09982        | 2.0       |
| LTA05-09 | 1250    | 1.266 | 0.00131         | 0.00019        | 0.00201         | 0.00001         | 0.04636         | 0.00586        | 1.3       |
| LTA05-10 | 1883    | 0.787 | 0.00118         | 0.00031        | 0.00020         | 0.00001         | 0.04228         | 0.00925        | 1.3       |
| LTA05-11 | 329     | 1.266 | 0.00258         | 0.00183        | 0.00022         | 0.00002         | 0.08544         | 0.05372        | 1.3       |
| LTA05-12 | 4076    | 2.439 | 0.00125         | 0.00021        | 0.00019         | 0.00001         | 0.04648         | 0.00668        | 1.3       |
| LTA05-13 | 543     | 0.595 | 0.00237         | 0.00117        | 0.00021         | 0.00002         | 0.08350         | 0.03431        | 1.4       |
| LTA05-14 | 348     | 1.053 | 0.00036         | 0.00200        | 0.00021         | 0.00003         | 0.01214         | 0.06589        | 1.3       |
| LTA05-15 | 1831    | 1.429 | 0.00128         | 0.00035        | 0.00020         | 0.00001         | 0.04663         | 0.01145        | 1.4       |
| LTA05-16 | 496     | 1.053 | 0.00099         | 0.00113        | 0.00019         | 0.00002         | 0.03859         | 0.04043        | 1.3       |
| LTA05-17 | 428     | 1.316 | 0.00096         | 0.00103        | 0.00020         | 0.00001         | 0.03527         | 0.03626        | 1.3       |
| LTA05-18 | 1124    | 0.787 | 0.00132         | 0.00042        | 0.00020         | 0.00001         | 0.04737         | 0.01352        | 1.3       |
| LTA05-19 | 1286    | 1.031 | 0.00071         | 0.00056        | 0.00019         | 0.00001         | 0.02878         | 0.02067        | 1.2       |
| LTA05-20 | 1160    | 1.176 | 0.00169         | 0.00041        | 0.00022         | 0.00001         | 0.05647         | 0.01144        | 1.3       |
| LTA05-21 | 460     | 0.787 | 0.00156         | 0.00032        | 0.00024         | 0.00001         | 0.04632         | 0.00824        | 1.6       |
| LTA05-22 | 1445    | 1.205 | 0.00128         | 0.00034        | 0.00020         | 0.00001         | 0.04668         | 0.01104        | 1.3       |
| LTA05-23 | 606     | 1.667 | 0.00070         | 0.00129        | 0.00021         | 0.00002         | 0.02384         | 0.04190        | 1.4       |
| LTA05-24 | 647     | 0.004 | 0.35987         | 0.00942        | 0.04255         | 0.00091         | 0.06133         | 0.00063        | 269       |
| LTA05-25 | 908     | 0.637 | 0.07379         | 0.00409        | 0.01161         | 0.00029         | 0.04609         | 0.00167        | 74        |
| LTA05-26 | 1119    | 1.205 | 0.00144         | 0.00038        | 0.00022         | 0.00001         | 0.04671         | 0.01117        | 1.4       |
| LTA05-27 | 352     | 1.429 | 0.00137         | 0.00130        | 0.00024         | 0.00002         | 0.04101         | 0.03587        | 1.5       |
| LTA05-28 | 540     | 1.515 | 0.00050         | 0.00095        | 0.00022         | 0.00002         | 0.01688         | 0.03070        | 1.4       |
| LTA05-29 | 970     | 1.136 | 0.00180         | 0.00075        | 0.00021         | 0.00001         | 0.06113         | 0.02289        | 1.4       |
| LTA05-30 | 726     | 1.149 | 0.00267         | 0.00089        | 0.00021         | 0.00001         | 0.09242         | 0.02691        | 1.4       |

Mean 206Pb/238U age = 1.36 ± 0.05 Ma (N = 38, MSWD = 1.7)
Table 3. (Continued)

| Spot | U (ppm) | Th/U | \(^{206}\text{Pb}/^{238}\text{U} \pm 1 s | \(^{207}\text{Pb}/^{235}\text{U} \pm 1 s | \(^{208}\text{Pb}/^{232}\text{U} \pm 1 s | \(^{207}\text{Pb}/^{206}\text{Pb} \pm 1 s | \(^{206}\text{Pb}/^{204}\text{Pb} \pm 1 s | \(^{206}\text{Pb}/^{208}\text{Pb} \pm 1 s | \(^{206}\text{Pb}/^{208}\text{Th} \pm 1 s |
|-------|---------|------|----------------------------------------|----------------------------------------|----------------------------------------|----------------------------------------|----------------------------------------|----------------------------------------|----------------------------------------|
| LTA05-05 (Kungkuan andesite) | | | | | | | | | |
| LTA05-31 | 800 | 0.075 | 4.66439 | 0.12448 | 0.29575 | 0.00731 | 0.11439 | 0.00119 | 0.08518 | 0.00217 |
| LTA05-33 | 1219 | 0.730 | 0.00356 | 0.00079 | 0.00040 | 0.0002 | 0.06490 | 0.01163 | 0.00012 | 0.00001 |
| LTA05-34 | 1642 | 0.787 | 0.00276 | 0.00033 | 0.00223 | 0.0001 | 0.08598 | 0.00711 | 0.00008 | 0.00001 |
| LTA05-35 | 556 | 0.521 | 0.00195 | 0.00084 | 0.00025 | 0.0001 | 0.05557 | 0.02196 | 0.00011 | 0.00001 |
| LTA05-36 | 1657 | 1.099 | 0.00228 | 0.00065 | 0.00023 | 0.0001 | 0.07056 | 0.01730 | 0.00007 | 0.00001 |
| LTA05-37 | 1178 | 1.136 | 0.00440 | 0.00215 | 0.00024 | 0.0004 | 0.13266 | 0.04675 | 0.00007 | 0.00001 |
| LTA05-38 | 713 | 1.205 | 0.00023 | 0.00060 | 0.00020 | 0.0001 | 0.00820 | 0.02102 | 0.00006 | 0.00001 |
| LTA05-39 | 234 | 0.613 | 0.00095 | 0.00190 | 0.00019 | 0.0002 | 0.03696 | 0.07044 | 0.00002 | 0.00003 |
| LTA05-40 | 1767 | 1.449 | 0.00137 | 0.00024 | 0.00021 | 0.0001 | 0.04642 | 0.00704 | 0.00008 | 0.00001 |
| LTA05-41 | 1412 | 2.083 | 0.00014 | 0.00031 | 0.00019 | 0.0001 | 0.00525 | 0.01138 | 0.00007 | 0.00001 |
| LTA05-42 | 232 | 0.508 | 0.00168 | 0.00051 | 0.00026 | 0.0002 | 0.04613 | 0.01157 | 0.00028 | 0.00011 |
| LTA05-43 | 935 | 0.917 | 0.00054 | 0.00048 | 0.00024 | 0.0001 | 0.01605 | 0.01367 | 0.00008 | 0.00001 |
| Mean | | | \(^{206}\text{Pb}/^{238}\text{U} \text{age} = 1.36 ± 0.05 Ma (N = 38, MSWD = 1.7) | | | | | | | |

| Spot | U (ppm) | Th/U | \(^{206}\text{Pb}/^{238}\text{U} \pm 1 s | \(^{207}\text{Pb}/^{235}\text{U} \pm 1 s | \(^{208}\text{Pb}/^{232}\text{U} \pm 1 s | \(^{207}\text{Pb}/^{206}\text{Pb} \pm 1 s | \(^{206}\text{Pb}/^{204}\text{Pb} \pm 1 s | \(^{206}\text{Pb}/^{208}\text{Pb} \pm 1 s | \(^{206}\text{Pb}/^{208}\text{Th} \pm 1 s |
|-------|---------|------|----------------------------------------|----------------------------------------|----------------------------------------|----------------------------------------|----------------------------------------|----------------------------------------|----------------------------------------|
| LTA06-01 | 1048 | 0.833 | 0.00107 | 0.00048 | 0.00017 | 0.0001 | 0.04654 | 0.01645 | 0.00007 | 0.00001 |
| LTA06-02 | 1040 | 0.813 | 0.00128 | 0.00016 | 0.00020 | 0.0001 | 0.04625 | 0.00470 | 0.00013 | 0.00003 |
| LTA06-03 | 1469 | 1.429 | 0.00121 | 0.00024 | 0.00019 | 0.0001 | 0.04678 | 0.00838 | 0.00007 | 0.00001 |
| LTA06-04 | 422 | 0.364 | 0.00448 | 0.00157 | 0.00021 | 0.0002 | 0.15217 | 0.04078 | 0.00011 | 0.00003 |
| LTA06-05 | 825 | 1.852 | 0.00203 | 0.00157 | 0.00018 | 0.0002 | 0.08339 | 0.05495 | 0.00005 | 0.00001 |
| LTA06-06 | 1835 | 1.818 | 0.00108 | 0.00027 | 0.00019 | 0.0001 | 0.04051 | 0.00826 | 0.00007 | 0.00001 |
| LTA06-07 | 1000 | 0.746 | 0.00116 | 0.00055 | 0.00019 | 0.0001 | 0.04524 | 0.01933 | 0.00008 | 0.00001 |
| LTA06-08 | 1370 | 0.917 | 0.00132 | 0.00024 | 0.00020 | 0.0001 | 0.04663 | 0.00738 | 0.00008 | 0.00001 |
| LTA06-09 | 589 | 0.746 | 0.00210 | 0.00085 | 0.00022 | 0.0001 | 0.06861 | 0.02541 | 0.00007 | 0.00001 |
| LTA06-10 | 1153 | 0.962 | 0.00090 | 0.00048 | 0.00019 | 0.0001 | 0.03364 | 0.01637 | 0.00006 | 0.00001 |
| Mean | | | \(^{206}\text{Pb}/^{238}\text{U} \text{age} = 1.24 ± 0.04 Ma (N = 27, MSWD = 1.2) | | | | | | | |
## Table 3. (Continued)

| Spot       | U (ppm) | Th/U | \(^{206}\text{Pb}/^{238}\text{U} \pm 1\) s | \(^{207}\text{Pb}/^{235}\text{U} \pm 1\) s | \(^{208}\text{Pb}/^{235}\text{U} \pm 1\) s | \(^{206}\text{Pb}/^{238}\text{Th} \pm 1\) s |
|------------|---------|------|------------------------------------------|------------------------------------------|------------------------------------------|------------------------------------------|
| LTA06-11   | 891     | 0.763| 0.00262                                 | 0.00155                                 | 0.00019                                 | 0.10055                                 |
| LTA06-12   | 861     | 1.282| 0.00132                                 | 0.00035                                 | 0.00021                                 | 0.04633                                 |
| LTA06-13   | 2278    | 0.575| 0.00061                                 | 0.00024                                 | 0.00022                                 | 0.02031                                 |
| LTA06-14   | 878     | 0.758| 0.00164                                 | 0.00059                                 | 0.00017                                 | 0.06895                                 |
| LTA06-15   | 1010    | 1.000| 0.00113                                 | 0.00069                                 | 0.00016                                 | 0.05021                                 |
| LTA06-16   | 477     | 1.042| 0.00015                                 | 0.00157                                 | 0.00022                                 | 0.05017                                 |
| LTA06-17   | 848     | 0.730| 0.00136                                 | 0.00066                                 | 0.00016                                 | 0.06193                                 |
| LTA06-18   | 487     | 1.250| 0.00208                                 | 0.00109                                 | 0.00022                                 | 0.06828                                 |
| LTA06-19   | 1196    | 1.299| 0.00127                                 | 0.00038                                 | 0.00020                                 | 0.04663                                 |
| LTA06-20   | 421     | 1.031| 0.00083                                 | 0.00113                                 | 0.00019                                 | 0.03252                                 |
| LTA06-21   | 478     | 0.909| 0.00189                                 | 0.00093                                 | 0.00019                                 | 0.07415                                 |
| LTA06-22   | 885     | 0.833| 0.00237                                 | 0.00084                                 | 0.00022                                 | 0.07956                                 |
| LTA06-23   | 987     | 1.020| 0.00086                                 | 0.00044                                 | 0.00019                                 | 0.03275                                 |
| LTA06-24   | 1654    | 1.266| 0.00119                                 | 0.00037                                 | 0.00018                                 | 0.04665                                 |
| LTA06-25   | 942     | 0.787| 0.00128                                 | 0.00060                                 | 0.00018                                 | 0.05064                                 |
| LTA06-26   | 1392    | 1.163| 0.00157                                 | 0.00077                                 | 0.00018                                 | 0.06351                                 |
| LTA06-27   | 847     | 0.714| 0.00010                                 | 0.00071                                 | 0.00018                                 | 0.00395                                 |

Mean \(^{206}\text{Pb}/^{238}\text{U} \) age = 1.24 ± 0.04 Ma (N = 27, MSWD = 1.2)

| Spot       | U (ppm) | Th/U | \(^{206}\text{Pb}/^{238}\text{U} \pm 1\) s | \(^{207}\text{Pb}/^{235}\text{U} \pm 1\) s | \(^{208}\text{Pb}/^{235}\text{U} \pm 1\) s | \(^{206}\text{Pb}/^{238}\text{Th} \pm 1\) s |
|------------|---------|------|------------------------------------------|------------------------------------------|------------------------------------------|------------------------------------------|
| LTA07-01   | 536     | 1.087| 0.00131                                 | 0.00051                                 | 0.00020                                 | 0.04671                                 |
| LTA07-02   | 577     | 1.695| 0.00331                                 | 0.00087                                 | 0.00019                                 | 0.12457                                 |
| LTA07-03   | 179     | 0.355| 0.00012                                 | 0.00020                                 | 0.00019                                 | 0.02776                                 |
| LTA07-04   | 671     | 0.794| 0.00076                                 | 0.00240                                 | 0.00076                                 | 0.04787                                 |
| LTA07-05   | 712     | 1.075| 0.00161                                 | 0.00079                                 | 0.00024                                 | 0.04787                                 |

Mean \(^{206}\text{Pb}/^{238}\text{U} \) age = 1.28 ± 0.06 Ma (N = 34, MSWD = 2.4)
| Spot         | U (ppm) | Th/U | 238Pb/235U ± 1 s | 236Pb/238U ± 1 s | 238Pb/236Pb ± 1 s | 206Pb/238U ± 1 s | Ages (Ma)  |
|-------------|---------|------|-----------------|-----------------|-----------------|-----------------|------------|
| LTA07-06    | 1078    | 1.111| 0.00061         | 0.00043         | 0.00019         | 0.0001          | 0.02376     | 0.01563    | 0.00006    | 0.00001    |
| LTA07-07    | 520     | 1.136| 0.00188         | 0.00098         | 0.00022         | 0.0001          | 0.06262     | 0.03010    | 0.00007    | 0.00001    |
| LTA07-08    | 966     | 2.703| 0.00088         | 0.00053         | 0.00018         | 0.0001          | 0.03506     | 0.01938    | 0.00006    | 0.00001    |
| LTA07-09    | 526     | 1.163| 0.00112         | 0.00033         | 0.00018         | 0.0001          | 0.04633     | 0.01165    | 0.00008    | 0.00002    |
| LTA07-10    | 769     | 0.139| 8.73984         | 0.20144         | 0.42862         | 0.00952         | 0.14789     | 0.00150    | 0.13205    | 0.00383    |
| LTA07-11    | 338     | 0.885| 0.00196         | 0.00145         | 0.00019         | 0.00002         | 0.07683     | 0.04969    | 0.00006    | 0.00001    |
| LTA07-12    | 1165    | 0.295| 0.00237         | 0.00061         | 0.00019         | 0.0001          | 0.08879     | 0.01918    | 0.00006    | .           |
| LTA07-13    | 724     | 0.532| 0.00142         | 0.00063         | 0.00020         | 0.0001          | 0.05099     | 0.02036    | 0.00007    | 0.00001    |
| LTA07-14    | 1057    | 1.471| 0.00036         | 0.00043         | 0.00019         | 0.0001          | 0.01368     | 0.01570    | 0.00006    | 0.00001    |
| LTA07-15    | 902     | 0.500| 0.00082         | 0.00051         | 0.00018         | 0.0001          | 0.03269     | 0.01871    | 0.00004    | 0.00001    |
| LTA07-16    | 360     | 0.752| 0.00105         | 0.00138         | 0.00021         | 0.0002          | 0.03671     | 0.04513    | 0.00006    | 0.00002    |
| LTA07-17    | 595     | 1.786| 0.00012         | 0.00098         | 0.00017         | 0.0001          | 0.00523     | 0.04243    | 0.00005    | 0.00001    |
| LTA07-18    | 402     | 1.266| 0.00710         | 0.00214         | 0.00021         | 0.0002          | 0.24778     | 0.04552    | 0.00007    | 0.00001    |
| LTA07-19    | 801     | 1.124| 0.00014         | 0.00063         | 0.00016         | 0.0001          | 0.00607     | 0.02697    | 0.00005    | 0.00001    |
| LTA07-20    | 912     | 2.500| 0.00021         | 0.00078         | 0.00021         | 0.0001          | 0.00717     | 0.02632    | 0.00006    | 0.00001    |
| LTA07-21    | 804     | 1.235| 0.00106         | 0.00026         | 0.00016         | 0.0001          | 0.04670     | 0.01060    | 0.00007    | 0.00001    |
| LTA07-22    | 430     | 0.285| 10.69786        | 0.25608         | 0.47113         | 0.01080         | 0.16470     | 0.00173    | 0.14204    | 0.00436    |
| LTA07-23    | 93      | 0.685| 9.26454         | 0.25554         | 0.44370         | 0.01111         | 0.15145     | 0.00182    | 0.13333    | 0.00537    |
| LTA07-24    | 1521    | 0.315| 0.00537         | 0.00138         | 0.00024         | 0.00002         | 0.16099     | 0.02982    | 0.00007    | 0.00001    |
| LTA07-25    | 962     | 1.299| 0.00134         | 0.00023         | 0.00021         | 0.0001          | 0.04645     | 0.00703    | 0.00008    | 0.00001    |
| LTA07-26    | 1221    | 2.326| 0.00094         | 0.00046         | 0.00020         | 0.00001         | 0.03387     | 0.01307    | 0.00007    | 0.00001    |
| LTA07-27    | 549     | 0.203| 9.84759         | 0.24665         | 0.45606         | 0.01000         | 0.15662     | 0.00171    | 0.15770    | 0.00715    |
| LTA07-28    | 840     | 0.290| 10.37167        | 0.24252         | 0.46576         | 0.00974         | 0.16153     | 0.00165    | 0.15146    | 0.00601    |
| LTA07-29    | 142     | 0.667| 7.46430         | 0.38127         | 0.40681         | 0.01041         | 0.13308     | 0.00418    | 0.11541    | 0.00277    |

LTA07 (Niutuzhan volc. breccia)

Mean 206Pb/238U age = 1.28 ± 0.06 Ma (N = 34, MSWD = 2.4)

Table 3. (Continued)
| Spot       | U (ppm) | Th/U | U-Th-Pb ratios | Ages (Ma)     |
|------------|---------|------|----------------|---------------|
| LTA07-30   | 103     | 0.216| 12.32573 0.36556 0.50340 0.01098 0.17764 0.00245 0.16404 0.01111 | 2628 47 2631 23 2630 28 3070 193 |
| LTA07-31   | 572     | 0.840| 0.00412 0.00141 0.00032 0.00002 0.09429 0.02639 0.0009 0.00001 | 2.0 0.1 1514 553 4.0 1.0 1.9 0.1 |
| LTA07-32   | 393     | 0.704| 0.00335 0.00198 0.00027 0.00003 0.09027 0.04581 0.00008 0.00002 | 1.7 0.2 1431 1053 3.0 2.0 1.6 0.5 |
| LTA07-33   | 578     | 1.190| 0.00109 0.00082 0.00016 0.00001 0.04789 0.03421 0.00005 0.00001 | 1.1 0.1 94 954 1.1 0.8 1.1 0.2 |
| LTA07-34   | 1092    | 1.695| 0.00160 0.00047 0.00023 0.00001 0.05119 0.01307 0.00008 0.00001 | 1.5 0.1 249 513 1.6 0.5 1.6 0.2 |
| LTA07-35   | 183     | 0.581| 0.00146 0.00195 0.00023 0.00002 0.04646 0.05852 0.00008 0.00006 | 1.5 0.1 21 1355 1.0 2.0 2.0 1.0 |
| LTA07-36   | 884     | 0.645| 0.00027 0.00055 0.00018 0.00001 0.01127 0.02240 0.00006 0.00001 | 1.2 0.1 -1251 933 0.3 0.6 1.2 0.2 |
| LTA07-37   | 1196    | 1.515| 0.00120 0.00049 0.00019 0.00001 0.04640 0.01678 0.00007 0.00001 | 1.2 0.1 18 580 1.2 0.5 1.4 0.2 |
| LTA07-38   | 536     | 0.571| 0.00057 0.00101 0.00018 0.00001 0.02221 0.03825 0.00004 0.00001 | 1.2 0.1 -648 1083 1.0 1.0 0.8 0.2 |
| LTA07-39   | 99      | 0.433| 13.08606 0.32010 0.51154 0.01122 0.18553 0.00198 0.16843 0.00665 | 2663 48 2703 19 2686 23 3146 115 |
| LTA07-40   | 392     | 1.852| 0.00211 0.00158 0.00020 0.00002 0.07490 0.04945 0.00008 0.00001 | 1.3 0.1 1066 1389 2.0 2.0 1.6 0.2 |
| LTA07-41   | 1185    | 2.083| 0.00131 0.00035 0.00020 0.00001 0.04676 0.01162 0.00007 0.00001 | 1.3 0.1 37 389 1.3 0.4 1.5 0.2 |
| LTA07-42   | 690     | 1.389| 0.00077 0.00068 0.00019 0.00001 0.02997 0.02506 0.00006 0.00001 | 1.2 0.1 -285 986 0.8 0.7 1.2 0.2 |
| LTA07-43   | 837     | 0.532| 0.00316 0.00100 0.00022 0.00001 0.10200 0.02847 0.00007 0.00001 | 1.4 0.1 1661 520 3.0 1.0 1.3 0.1 |
| LTA07-44   | 4104    | 1.429| 0.00149 0.00047 0.00023 0.00001 0.04674 0.01301 0.00008 0.00001 | 1.5 0.1 36 439 1.5 0.5 1.6 0.1 |
| LTA07-45   | 660     | 0.476| 0.00014 0.00072 0.00017 0.00001 0.00596 0.03034 0.00003 0.00001 | 1.1 0.1 -1590 1115 0.1 0.7 0.6 0.2 |

Mean $^{206}$Pb/$^{238}$U age = 1.28 ± 0.06 Ma (N = 34, MSWD = 2.4)

| Spot       | U (ppm) | Th/U | U-Th-Pb ratios | Ages (Ma)     |
|------------|---------|------|----------------|---------------|
| LTS01-01   | 600     | 1.429| 0.00120 0.00072 0.00019 0.00001 0.04655 0.02594 0.00007 0.00001 | 1.2 0.1 26 972 1.2 0.7 1.4 0.2 |
| LTS01-02   | 681     | 1.316| 0.00110 0.00012 0.00017 0.00001 0.04640 0.00437 0.00010 0.00002 | 1.1 0.1 18 177 1.1 0.1 2.0 0.3 |
| LTS01-03   | 682     | 2.439| 0.00123 0.00049 0.00019 0.00001 0.04670 0.01744 0.00007 0.00001 | 1.2 0.1 34 683 1.2 0.5 1.4 0.2 |
| LTS01-04   | 1624    | 2.439| 0.00118 0.00052 0.00018 0.00001 0.04661 0.01883 0.00007 0.00001 | 1.2 0.1 30 696 1.2 0.5 1.4 0.2 |
| LTS01-05   | 898     | 1.754| 0.00067 0.00079 0.00017 0.00001 0.02867 0.03230 0.00008 0.00001 | 1.1 0.1 -343 1003 0.7 0.8 1.6 0.2 |
| LTS01-06   | 443     | 1.351| 0.00040 0.00132 0.00020 0.00002 0.01452 0.04661 0.00007 0.00001 | 1.3 0.1 -1060 1192 1.0 1.0 1.4 0.2 |

Mean $^{206}$Pb/$^{238}$U age = 1.20 ± 0.04 Ma (N = 59, MSWD = 1.8)
| Spot     | U (ppm) | Th/U | 238U/235U ± 1 s | 238U/234U ± 1 s | 238U/236U ± 1 s | 238U/235Th ± 1 s | Ages (Ma) | 238U/235U ± 1 s | 238U/236U ± 1 s | 238U/235Th ± 1 s |
|----------|---------|------|----------------|----------------|----------------|----------------|-----------|----------------|----------------|----------------|
| LTS01-07 | 1002    | 1.087| 0.00117        | 0.0024         | 0.0018         | 0.00001        | 0.0061    | 23             | 1.2            | 0.13           |
| LTS01-08 | 700     | 0.680| 0.00132        | 0.00057        | 0.0018         | 0.00001        | 0.0052    | -303           | 1.2            | 0.15           |
| LTS01-10 | 1389    | 1.393| 0.00177        | 0.00136        | 0.0019         | 0.00002        | 0.0390    | 1388           | 1.0            | 0.15           |
| LTS01-11 | 1099    | 1.099| 0.00295        | 0.00153        | 0.0018         | 0.00002        | 0.0118    | 121           | 1.0            | 0.15           |
| LTS01-12 | 1333    | 1.333| 0.00228        | 0.00150        | 0.0018         | 0.00002        | 0.0911    | 121            | 1.0            | 0.15           |
| LTS01-13 | 1961    | 1.010| 0.00103        | 0.00044        | 0.0016         | 0.00001        | 0.0465    | 121            | 1.0            | 0.15           |
| LTS01-14 | 1299    | 1.012| 0.00107        | 0.00080        | 0.0017         | 0.00002        | 0.0464    | 121            | 1.0            | 0.15           |
| LTS01-15 | 2778    | 1.919| 0.00038        | 0.00070        | 0.0019         | 0.00001        | 0.0140    | 121            | 1.0            | 0.15           |
| LTS01-16 | 1538    | 1.538| 0.00133        | 0.00009        | 0.0021         | 0.00001        | 0.0464    | 121            | 1.0            | 0.15           |
| LTS01-17 | 2174    | 2.174| 0.00143        | 0.00067        | 0.0018         | 0.00001        | 0.0562    | 121            | 1.0            | 0.15           |
| LTS01-18 | 1087    | 1.087| 0.00161        | 0.00080        | 0.0018         | 0.00001        | 0.0656    | 121            | 1.0            | 0.15           |
| LTS01-19 | 1449    | 1.449| 0.00126        | 0.00114        | 0.0015         | 0.00001        | 0.0604    | 121            | 1.0            | 0.15           |
| LTS01-20 | 1250    | 1.250| 0.00241        | 0.00122        | 0.0023         | 0.00002        | 0.0752    | 121            | 1.0            | 0.15           |
| LTS01-21 | 877     | 0.877| 0.00128        | 0.00033        | 0.0020         | 0.00001        | 0.0462    | 121            | 1.0            | 0.15           |
| LTS01-22 | 552     | 0.552| 0.00022        | 0.00044        | 0.0022         | 0.00001        | 0.0075    | 121            | 1.0            | 0.15           |
| LTS01-23 | 1587    | 1.587| 0.0037         | 0.00080        | 0.0017         | 0.00001        | 0.0155    | 121            | 1.0            | 0.15           |
| LTS01-24 | 909     | 0.909| 0.00336        | 0.00200        | 0.0016         | 0.00002        | 0.1521    | 121            | 1.0            | 0.15           |
| LTS01-25 | 990     | 0.990| 0.00083        | 0.00142        | 0.0020         | 0.00002        | 0.0306    | 121            | 1.0            | 0.15           |
| LTS01-26 | 1316    | 1.316| 0.00013        | 0.00035        | 0.0017         | 0.00001        | 0.0056    | 121            | 1.0            | 0.15           |
| LTS01-27 | 1887    | 1.887| 0.00114        | 0.00038        | 0.0018         | 0.00001        | 0.0467    | 121            | 1.0            | 0.15           |
| LTS01-28 | 980     | 0.980| 0.00152        | 0.00164        | 0.0020         | 0.00002        | 0.0539    | 121            | 1.0            | 0.15           |
| LTS01-29 | 2222    | 2.222| 0.00129        | 0.00035        | 0.0020         | 0.00001        | 0.0473    | 121            | 1.0            | 0.15           |
| LTS01-30 | 1639    | 1.639| 0.00086        | 0.00031        | 0.0018         | 0.00001        | 0.0348    | 121            | 1.0            | 0.15           |

Mean 238U/235U age = 1.2 ± 0.04 Ma (N = 59, MSWD = 1.8)
Table 3. (Continued)

| Spot       | U (ppm) | Th/U | $^{206}\text{Pb}/^{238}\text{U}$ ± 1 s | $^{207}\text{Pb}/^{235}\text{U}$ ± 1 s | $^{207}\text{Pb}/^{206}\text{Pb}$ ± 1 s | $^{208}\text{Pb}/^{232}\text{Th}$ ± 1 s | Ages (Ma) |
|------------|---------|------|--------------------------------------|--------------------------------------|--------------------------------------|--------------------------------------|------------|
| LTS01-31   | 794     | 1.136| 0.00060                              | 0.00072                              | 0.00020                              | 0.00001                              | 0.02241    | 0.02589                             | 0.00020 | 0.00007                             | 0.0001 | 0.7                              |
| LTS01-32   | 423     | 1.613| 0.00515                              | 0.00225                              | 0.00017                              | 0.0003                               | 0.22294    | 0.06432                             | 0.00014 | 0.00002                             |        | 1.3                              |
| LTS01-33   | 1077    | 1.613| 0.00121                              | 0.00025                              | 0.00019                              | 0.0001                               | 0.06432    | 0.00005                             | 0.00007 | 0.00001                             |        | 1.2                              |
| LTS01-34   | 700     | 1.299| 0.00044                              | 0.00067                              | 0.00018                              | 0.0001                               | 0.01789    | 0.02635                             | 0.00005 | 0.00001                             |        | 1.2                              |
| LTS01-35   | 325     | 1.754| 0.00593                              | 0.00285                              | 0.00027                              | 0.0004                               | 0.15980    | 0.05645                             | 0.00015 | 0.00002                             |        | 1.7                              |
| LTS01-36   | 325     | 0.909| 0.00114                              | 0.00143                              | 0.00018                              | 0.0002                               | 0.04547    | 0.05254                             | 0.00004 | 0.00001                             |        | 1.2                              |
| LTS01-37   | 588     | 1.099| 0.00127                              | 0.00062                              | 0.00020                              | 0.0001                               | 0.04688    | 0.02154                             | 0.00007 | 0.00001                             |        | 1.3                              |
| LTS01-38   | 764     | 1.163| 0.00040                              | 0.00063                              | 0.00018                              | 0.0001                               | 0.01637    | 0.02497                             | 0.00006 | 0.00001                             |        | 1.2                              |
| LTS01-39   | 2073    | 1.852| 0.00079                              | 0.00023                              | 0.00017                              | 0.0001                               | 0.03449    | 0.00826                             | 0.00006 | 0.00001                             |        | 1.1                              |
| LTS01-40   | 494     | 1.235| 0.00019                              | 0.00146                              | 0.00013                              | 0.0002                               | 0.01086    | 0.08195                             | 0.00004 | 0.00001                             |        | 0.8                              |
| LTS01-41   | 768     | 1.587| 0.00036                              | 0.00080                              | 0.00020                              | 0.0001                               | 0.01334    | 0.02905                             | 0.00007 | 0.00001                             |        | 1.3                              |
| LTS01-42   | 473     | 1.299| 0.00018                              | 0.00149                              | 0.00019                              | 0.0002                               | 0.00672    | 0.05499                             | 0.00010 | 0.00001                             |        | 1.2                              |
| LTS01-43   | 319     | 0.971| 0.00012                              | 0.00017                              | 0.00018                              | 0.0003                               | 0.04621    | 0.06558                             | 0.00012 | 0.00007                             |        | 1.1                              |
| LTS01-44   | 1463    | 2.857| 0.00020                              | 0.00035                              | 0.00019                              | 0.0001                               | 0.00761    | 0.01296                             | 0.00007 | 0.00001                             |        | 1.2                              |
| LTS01-45   | 402     | 1.563| 0.00014                              | 0.00015                              | 0.00018                              | 0.0002                               | 0.00564    | 0.06107                             | 0.00005 | 0.00001                             |        | 1.2                              |
| LTS01-46   | 797     | 1.695| 0.00013                              | 0.00037                              | 0.00021                              | 0.0001                               | 0.04651    | 0.01167                             | 0.00007 | 0.00001                             |        | 1.3                              |
| LTS01-47   | 577     | 1.493| 0.00070                              | 0.00077                              | 0.00019                              | 0.0001                               | 0.02625    | 0.02764                             | 0.00007 | 0.00001                             |        | 1.2                              |
| LTS01-48   | 303     | 1.031| 0.00047                              | 0.00025                              | 0.00029                              | 0.0004                               | 0.10207    | 0.05165                             | 0.00017 | 0.00002                             |        | 1.9                              |
| LTS01-49   | 574     | 1.099| 0.00183                              | 0.00076                              | 0.00020                              | 0.0001                               | 0.06774    | 0.02513                             | 0.00007 | 0.00001                             |        | 1.3                              |
| LTS01-50   | 1543    | 1.205| 0.00120                              | 0.00031                              | 0.00017                              | 0.0001                               | 0.05144    | 0.01065                             | 0.00006 | 0.00001                             |        | 1.1                              |
| LTS01-51   | 355     | 1.266| 0.00042                              | 0.00119                              | 0.00017                              | 0.0002                               | 0.01752    | 0.04779                             | 0.00005 | 0.00001                             |        | 1.1                              |
| LTS01-52   | 216     | 1.149| 0.00039                              | 0.00020                              | 0.00021                              | 0.0002                               | 0.01324    | 0.06846                             | 0.00013 | 0.00002                             |        | 1.4                              |
| LTS01-53   | 832     | 1.176| 0.00040                              | 0.00053                              | 0.00022                              | 0.0001                               | 0.01308    | 0.01680                             | 0.00007 | 0.00001                             |        | 1.4                              |
| LTS01-54   | 305     | 1.136| 0.00053                              | 0.00017                              | 0.00019                              | 0.0002                               | 0.01997    | 0.06368                             | 0.00006 | 0.00001                             |        | 1.2                              |

Mean $^{206}\text{Pb}/^{238}\text{U}$ age = 1.20 ± 0.04 Ma (N = 59, MSWD = 1.8)

LTS-01 (beach sand)
| Spot   | U (ppm) | Th/U | $^{206}\text{Pb}/^{238}\text{U}$ ± 1 s | $^{208}\text{Pb}/^{238}\text{U}$ ± 1 s | $^{206}\text{Pb}/^{208}\text{Th}$ ± 1 s | $^{207}\text{Pb}/^{206}\text{Pb}$ ± 1 s | $^{206}\text{Pb}/^{235}\text{Th}$ ± 1 s | Ages (Ma) |
|--------|---------|------|------------------------------------------|------------------------------------------|------------------------------------------|------------------------------------------|------------------------------------------|------------|
| LTS01-55 | 701.568 |     | 0.00040 0.00063 0.00024 0.00001 0.01216 0.01870 0.00008 0.00001 | | | | | 1.5 0.1 -1198 871 0.4 0.6 1.6 0.2 |
| LTS01-56 | 1093.236 |     | 0.00046 0.00046 0.00017 0.00001 0.01917 0.01816 0.00006 0.00001 | | | | | 1.1 0.1 -804 765 0.5 0.5 1.2 0.2 |
| LTS01-57 | 255.787 |     | 0.00148 0.00199 0.00013 0.00002 0.08188 0.09891 0.00006 0.00002 | | | | | 0.8 0.1 1243 2107 2.0 2.0 1.2 0.4 |
| LTS01-58 | 1676.2128 |     | 0.00152 0.00048 0.00020 0.00001 0.05460 0.01483 0.00007 0.00001 | | | | | 1.3 0.1 396 515 1.5 0.5 1.4 0.2 |
| LTS01-59 | 574.901 |     | 0.00033 0.00083 0.00018 0.00001 0.01340 0.03303 0.00006 0.00001 | | | | | 1.2 0.1 -1124 1064 0.3 0.8 1.2 0.2 |

Mean $^{206}\text{Pb}/^{238}\text{U}$ age = 1.20 ± 0.04 Ma (N = 59, MSWD = 1.8)

| LTS02-01 | 297.617 |     | 0.21155 0.00908 0.03066 0.00079 0.05009 0.00114 0.01085 0.00047 | | | | | 195 5 199 51 195 8 218 9 |
| LTS02-02 | 240.535 |     | 0.24931 0.00664 0.03584 0.00077 0.05045 0.00960 0.01294 0.00037 | | | | | 227 5 216 25 226 5 260 7 |
| LTS02-03 | 355.1053 |     | 0.00112 0.00133 0.00020 0.00002 0.04950 0.04448 0.00007 0.00001 | | | | | 1.3 0.1 -261 1234 1.0 1.0 1.4 0.2 |
| LTS02-04 | 334.1220 |     | 0.00048 0.00156 0.00016 0.00002 0.02253 0.07070 0.00007 0.00001 | | | | | 1.0 0.1 -632 1643 1.0 2.0 1.4 0.2 |
| LTS02-05 | 215.090 |     | 0.00384 0.00298 0.00021 0.00003 0.13374 0.08699 0.00010 0.00003 | | | | | 1.4 0.2 2148 1360 4.0 3.0 2.0 0.6 |
| LTS02-06 | 1297.1961 |     | 0.00122 0.00007 0.00019 0.00001 0.04649 0.00170 0.00008 0.00001 | | | | | 1.2 0.1 23 74 1.2 0.1 1.6 0.2 |
| LTS02-07 | 406.714 |     | 0.00057 0.00161 0.00021 0.00002 0.01970 0.05396 0.00007 0.00002 | | | | | 1.4 0.1 -777 1341 1.0 2.0 1.4 0.4 |
| LTS02-08 | 1081.1563 |     | 0.00055 0.00054 0.00019 0.00001 0.02132 0.01993 0.00007 0.00001 | | | | | 1.2 0.1 -693 792 0.6 0.5 1.4 0.2 |
| LTS02-09 | 235.1695 |     | 0.14298 0.00446 0.01986 0.00043 0.05221 0.00079 0.00068 0.00021 | | | | | 127 3 295 35 136 4 138 4 |
| LTS02-10 | 485.1250 |     | 0.00106 0.00099 0.00020 0.00001 0.03925 0.03490 0.00008 0.00001 | | | | | 1.3 0.1 -334 1045 1.0 1.0 1.6 0.2 |
| LTS02-11 | 565.200 |     | 8.75872 0.22735 0.40479 0.00814 0.15693 0.00185 0.11299 0.00025 | | | | | 2191 37 2423 29 2313 24 2164 41 |
| LTS02-12 | 329.1149 |     | 0.00197 0.00145 0.00024 0.00002 0.06076 0.04023 0.00008 0.00001 | | | | | 1.5 0.1 631 1129 2.0 1.0 1.6 0.2 |
| LTS02-13 | 1642.395 |     | 0.27225 0.00609 0.03844 0.00080 0.05137 0.00050 0.01321 0.00042 | | | | | 243 5 257 24 244 5 265 8 |
| LTS02-14 | 1320.2857 |     | 0.01249 0.00509 0.00053 0.00006 0.17079 0.05241 0.00015 0.00001 | | | | | 3.4 0.4 2565 719 13 5 3.0 0.2 |
| LTS02-15 | 109.746 |     | 1.13416 0.02961 0.12647 0.00280 0.06504 0.00075 0.04210 0.00124 | | | | | 768 16 776 25 770 14 834 24 |
| LTS02-16 | 339.1099 |     | 0.30441 0.00721 0.04208 0.00088 0.05247 0.00054 0.01436 0.00037 | | | | | 266 5 306 24 270 6 288 7 |
| LTS02-17 | 318.1587 |     | 0.28915 0.00697 0.03954 0.00083 0.05305 0.00056 0.01376 0.00036 | | | | | 250 5 331 23 258 5 276 7 |

Mean $^{206}\text{Pb}/^{238}\text{U}$ age = 1.27 ± 0.09 Ma (N = 15, MSWD = 2.7)
| Spot         | U (ppm) | Th/U   | $^{206}\text{Pb}^{238}\text{U}$ ± 1 s | $^{206}\text{Pb}^{238}\text{Pb}$ ± 1 s | $^{206}\text{Pb}^{232}\text{Th}$ ± 1 s | Ages (Ma) |
|--------------|---------|--------|--------------------------------------|--------------------------------------|--------------------------------------|------------|
| LTS02-18     | 3696    | 0.274  | 0.49135                              | 0.02207                              | 0.06436                              | 0.0132     |
| LTS02-19     | 4979    | 2.000  | 0.00139                              | 0.00011                              | 0.00024                              | 0.0001     |
| LTS02-20     | 341     | 1.163  | 0.00004                              | 0.00232                              | 0.00033                              | 0.00081    |
| LTS02-21     | 678     | 1.124  | 0.00072                              | 0.00065                              | 0.00023                              | 0.02264    |
| LTS02-22     | 259     | 1.587  | 0.29138                              | 0.00734                              | 0.03914                              | 0.0083     |
| LTS02-23     | 482     | 1.408  | 0.00191                              | 0.00107                              | 0.00017                              | 0.08188    |
| LTS02-24     | 763     | 0.806  | 0.00028                              | 0.00072                              | 0.00020                              | 0.0001     |
| LTS02-25     | 804     | 1.449  | 0.00010                              | 0.00076                              | 0.00018                              | 0.00400    |
| LTS02-26     | 787     | 0.990  | 0.00004                              | 0.00054                              | 0.00019                              | 0.00019    |
| LTS02-27     | 304     | 0.840  | 0.00134                              | 0.00143                              | 0.00016                              | 0.00611    |

Mean $^{206}\text{Pb}^{238}\text{U}$ age = 1.27 ± 0.09 Ma (N = 15, MSWD = 2.7)

| LTS03-01     | 494     | 0.990  | 0.00038                              | 0.00028                              | 0.00016                              | 0.00003    |
| LTS03-02     | 546     | 0.971  | 0.00012                              | 0.00039                              | 0.00019                              | 0.00465    |
| LTS03-03     | 585     | 1.042  | 0.00065                              | 0.00083                              | 0.00023                              | 0.02053    |
| LTS03-04     | 2156    | 1.538  | 0.00012                              | 0.00067                              | 0.00020                              | 0.00187    |
| LTS03-05     | 1196    | 1.724  | 0.00012                              | 0.00039                              | 0.00020                              | 0.00456    |
| LTS03-06     | 554     | 1.149  | 0.00012                              | 0.00084                              | 0.00019                              | 0.00001    |
| LTS03-07     | 1046    | 0.800  | 0.00013                              | 0.00055                              | 0.00020                              | 0.00047    |
| LTS03-08     | 1249    | 0.769  | 0.00020                              | 0.00040                              | 0.00020                              | 0.00074    |
| LTS03-09     | 812     | 1.449  | 0.00013                              | 0.00036                              | 0.00021                              | 0.00465    |
| LTS03-10     | 654     | 1.205  | 0.00012                              | 0.00078                              | 0.00020                              | 0.00465    |
| LTS03-11     | 671     | 1.370  | 0.00015                              | 0.00067                              | 0.00019                              | 0.00589    |
| LTS03-12     | 974     | 1.299  | 0.00015                              | 0.00050                              | 0.00019                              | 0.00587    |

Mean $^{206}\text{Pb}^{238}\text{U}$ age = 1.28 ± 0.04 Ma (N = 28, MSWD = 1.0)
Table 3. (Continued)

| Spot       | U (ppm) | Th/U | $^{206}\text{Pb}/^{238}\text{U}$ ± 1 s | $^{206}\text{Pb}/^{208}\text{Pb}$ ± 1 s | $^{207}\text{Pb}/^{206}\text{Pb}$ ± 1 s | $^{208}\text{Pb}/^{232}\text{Th}$ ± 1 s | Ages (Ma) |
|------------|---------|------|---------------------------------------|---------------------------------------|---------------------------------------|---------------------------------------|-----------|
| LTS03-13   | 989     | 1.266 | 0.00152 0.00065 0.00020 0.00001 0.05438 0.02124 0.00006 0.00001 | 1.3 0.1 387 728 1.5 0.7 1.3 0.1 |
| LTS03-14   | 615     | 1.087 | 0.00120 0.00071 0.00018 0.00001 0.04723 0.02584 0.00006 0.00001 | 1.2 0.1 61 839 1.2 0.7 1.2 0.2 |
| LTS03-15   | 416     | 0.800 | 0.00107 0.00029 0.00017 0.00001 0.04626 0.01109 0.00010 0.00004 | 1.1 0.1 11 372 1.1 0.3 2.1 0.8 |
| LTS03-16   | 839     | 1.316 | 0.00138 0.00068 0.00022 0.00011 0.04621 0.02090 0.00007 0.00001 | 1.4 0.1 9 782 1.4 0.7 1.4 0.2 |
| LTS03-17   | 885     | 1.429 | 0.00129 0.00031 0.00020 0.00001 0.04637 0.01005 0.00008 0.00001 | 1.3 0.1 17 351 1.3 0.3 1.6 0.2 |
| LTS03-18   | 365     | 1.042 | 0.00049 0.00136 0.00019 0.00001 0.01889 0.05065 0.00004 0.00001 | 1.2 0.1 -819 1260 1.0 1.0 0.8 0.2 |
| LTS03-19   | 238     | 0.794 | 0.00168 0.00135 0.00026 0.00002 0.04616 0.03445 0.00015 0.00008 | 1.7 0.2 6 959 2.0 1.0 3.0 2.0 |
| LTS03-20   | 186     | 1.224 | 0.00257 0.00115 0.00021 0.00002 0.08723 0.03176 0.00008 0.00001 | 1.4 0.1 1366 714 3.0 1.0 1.6 0.2 |
| LTS03-21   | 306     | 1.111 | 0.00328 0.00167 0.00019 0.00001 0.12548 0.05249 0.00005 0.00001 | 1.2 0.1 2036 1128 3.0 2.0 1.1 0.1 |
| LTS03-22   | 248     | 1.224 | 0.00245 0.00095 0.00022 0.00011 0.08188 0.02845 0.00007 0.00001 | 1.4 0.1 1243 794 2.5 1.0 1.4 0.2 |
| LTS03-23   | 385     | 1.351 | 0.00052 0.00053 0.00018 0.00001 0.02038 0.01976 0.00006 0.00001 | 1.2 0.1 -741 749 0.5 0.5 1.2 0.2 |
| LTS03-24   | 431     | 1.667 | 0.00119 0.00010 0.00010 0.00001 0.04660 0.02656 0.00007 0.00001 | 1.2 0.1 29 127 1.2 0.1 1.5 0.2 |
| LTS03-25   | 565     | 1.000 | 0.00128 0.00078 0.00019 0.00002 0.04802 0.02646 0.00006 0.00002 | 1.2 0.1 100 855 1.3 0.8 1.3 0.3 |
| LTS03-26   | 389     | 0.943 | 0.00138 0.00210 0.00022 0.00003 0.04630 0.06534 0.00011 0.00006 | 1.4 0.2 13 1397 1.0 2.0 2.0 1.0 |
| LTS03-27   | 654     | 1.266 | 0.00035 0.00062 0.00020 0.00001 0.01253 0.02163 0.00005 0.00001 | 1.3 0.1 -1176 889 0.4 0.6 1.0 0.2 |
| LTS03-28   | 954     | 0.990 | 0.00050 0.00044 0.00018 0.00001 0.02008 0.01667 0.00006 0.00001 | 1.2 0.1 -757 734 0.5 0.4 1.2 0.2 |

Mean $^{206}\text{Pb}/^{238}\text{U}$ age = 1.28 ± 0.04 Ma (N = 28, MSWD = 1.0)
Fig. 7. Concordia diagrams of zircons from the Lutao samples.

Fig. 8. $^{206}\text{Pb}/^{238}\text{U}$ age spectra and weighted mean values of Lutao volcanic rocks (a to g) and river/beach sands (h to j). The numerical value (N) denotes the number of zircon grains analyzed and the analytical error bars are 2σ.
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The zircon U-Pb ages, confirming the geological map that suggests the Ameishan volcanic breccia is the oldest volcanic unit (Fig. 1a), are in good agreement with an Ar-Ar age of 1.4 ± 0.1 Ma (Lo et al. 1994) and are broadly consistent with or slightly older than the zircon fission-track ages of 1.7 - 0.9 Ma (Yang et al. 1995) and, apparently younger than the K-Ar ages of 4.3 - 2.1 Ma (Richard et al. 1986). Note that each sample has a slightly older zircon, with \(^{206}\text{Pb}/^{238}\text{U}\) age dated at 2.4 ± 0.1 and 2.2 ± 0.1 Ma (Table 3), respectively, which are interpreted to be xenocrysts captured from somewhat earlier magmatic activities. In addition, each sample holds several grains of much older U-Pb ages (Table 3), interpreted as inherited zircons that will be discussed collectively in the discussion section.

4.1.2 Niutzushan Andesite

Sample LTA-07 from this unit yielded a weighted mean \(^{206}\text{Pb}/^{238}\text{U}\) age of 1.28 ± 0.06 Ma (n = 35; MSWD = 2.4; Fig. 8g). The zircon U-Pb age is slightly younger than an Ar-Ar age of 1.5 ± 0.2 Ma (Lo et al. 1994) and broadly coeval with the zircon fission-track ages of 1.2 - 1.0 Ma (Yang et al. 1995). Along with ten grains of inherited zircons aged from 2139 to 2703 Ma, this sample has a xenocryst zircon grain with \(^{206}\text{Pb}/^{238}\text{U}\) age dated at 2.0 ± 0.1 Ma (Table 3).

4.1.3 Kungkuan Andesite

Three samples were collected from this unit. They are (1) LTA-04 yielding a weighted mean \(^{206}\text{Pb}/^{238}\text{U}\) age of 1.25 ± 0.05 Ma (n = 30; MSWD = 1.5; Fig. 8d), (2) LTA-05 yielding a weighted mean \(^{206}\text{Pb}/^{238}\text{U}\) age of 1.36 ± 0.05 Ma (n = 38; MSWD = 1.7; Fig. 8e), and (3) LTA-06 yielding a weighted mean \(^{206}\text{Pb}/^{238}\text{U}\) age of 1.24 ± 0.04 Ma (n = 27; MSWD = 1.2; Fig. 8f). These zircon U-Pb ages are older than the zircon fission-track ages of 0.8 - 0.5 Ma (Yang et al. 1995) and younger than the K-Ar ages of 2.9 - 1.9 Ma (Richard et al. 1986). There are four zircon grains of apparently older ages present in sample LTA-05, while no inherited zircon is observed in the other two samples (Table 3).

4.1.4 Huoshaoshan Andesite

Sample LTA-01 from this unit yielded a weighted mean \(^{206}\text{Pb}/^{238}\text{U}\) age of 1.24 ± 0.08 Ma (n = 29; MSWD = 3.2; Fig. 8a), which is slightly older than or broadly in accord with a zircon fission-track age of 1.0 ± 0.3 Ma (Yang et al. 1995). We note that two zircon grains gave the youngest \(^{206}\text{Pb}/^{238}\text{U}\) dates of 0.8 ± 0.1 and 0.9 ± 0.1 Ma (Table 3), confirming the classification by Chen et al. (1994a) that the Huoshaoshan andesite is the youngest volcanic unit in Lutao. Four inherited zircon grains of apparently older U-Pb ages are observed from this sample (Table 3).

4.1.5 Sands

Both samples LTS-01 (beach sands) and LTS-03 (river sands) hold exclusively young zircons that yielded weighted mean \(^{206}\text{Pb}/^{238}\text{U}\) ages of 1.20 ± 0.04 Ma (n = 59; MSWD = 1.8; Fig. 8h) and 1.28 ± 0.04 Ma (n = 28; MSWD = 1.1; Fig. 9j), respectively. We note that the two youngest grains, both with \(^{206}\text{Pb}/^{238}\text{U}\) ages dated at 0.8 ± 0.1 Ma (Table 3), are observed in sample LTS-01. By contrast, sample LTS-02 (river sands) contains not only young (n = 15) but also older (n = 10) zircons, with the former giving a similar weighted mean \(^{206}\text{Pb}/^{238}\text{U}\) age of 1.27 ± 0.09 Ma (n = 15; MSWD = 2.7; Fig. 8i) while the latter aging rather widely from 2.1 to 2423 Ma (Table 3).
4.2 Lanyu

In Lanyu, various though limited amounts of zircon separates were obtained from five volcanic samples from the four volcanic units and from the two sands as well for U-Pb age determination. The results are summarized in Table 1, listed grain by grain in Table 4 and plotted in concordia and age distribution diagrams (Figs. 9 and 10). All the dated zircons have high U concentrations (114 - 2036 ppm) coupled with high Th/U ratios (2.4 - 0.4), and thus are typical of igneous origin. Below we describe the results of the volcanic rocks and sands, from bottom to top following the geological map (Fig. 1b). Also, ages obtained by other methods from each volcanic unit in previous studies will be outlined for comparison.

4.2.1 Lungtouyen Volcanic Breccia

Sample LYA-03 from this bottom volcanic unit is actually a basalt (Table 1) that yielded only few grains of zircon separates giving a weighted mean $^{206}\text{Pb}/^{238}\text{U}$ age of $2.35 \pm 0.21$ Ma ($n = 4; \text{MSWD} = 0.3$; Fig. 10b). This age is much younger than the K-Ar ages of 4.9 - 3.7 Ma (Richard et al. 1986). In addition, there are three grains of old xenocrysts or inherited zircons, including two of Cretaceous and one of Paleoproterozoic ages (Table 4).

4.2.2 Tungching Andesite

Sample LYA-02 from this “andesite” unit is, unfortunately, also of basaltic composition (Table 1). Nineteen grains of zircon were obtained for U-Pb age determination that, however, yielded no magmatic age (Table 4). All these zircons are therefore interpreted as xenocrysts of inherited origin, with the two youngest grains dated at $7.0 \pm 0.5$ and $7.2 \pm 0.5$ Ma, respectively, and an additional grain at $14.8 \pm 0.6$ Ma, interpreted as crystallizing from earlier...
| Spot    | U (ppm) | Th/U | \(^{207}\text{Pb}/^{206}\text{U}\) ± 1 s | \(^{206}\text{Pb}/^{206}\text{U}\) ± 1 s | \(^{206}\text{Pb}/^{207}\text{Pb}\) ± 1 s | \(^{207}\text{Pb}/^{206}\text{Th}\) ± 1 s | \(^{206}\text{Pb}/^{206}\text{U}\) | \(^{206}\text{Pb}/^{207}\text{Pb}\) | \(^{207}\text{Pb}/^{206}\text{Th}\) |
|---------|---------|------|----------------|----------------|----------------|----------------|----------------|----------------|----------------|
| LYA01-01| 219     | 1.205| 0.00889        | 0.00546        | 0.00038        | 0.00008        | 0.165532       | 0.07412        | 0.00034        |
| LYA01-02| 346     | 0.144| 7.38010        | 0.16142        | 0.39620        | 0.00781        | 0.13511        | 0.00129        | 0.11391        |
| LYA01-03| 691     | 1.010| 11.02703       | 0.24986        | 0.48585        | 0.01056        | 0.16464        | 0.00164        | 0.14612        |
| LYA01-04| 776     | 0.314| 0.21562        | 0.00508        | 0.03027        | 0.00064        | 0.05167        | 0.00053        | 0.01059        |
| LYA01-05| 574     | 1.515| 0.00318        | 0.00104        | 0.00039        | 0.00002        | 0.05918        | 0.01668        | 0.00012        |
| LYA01-06| 181     | 0.389| 0.020671       | 0.00648        | 0.02995        | 0.00065        | 0.05006        | 0.00076        | 0.01029        |
| LYA01-07| 166     | 0.730| 0.10240        | 0.00453        | 0.01501        | 0.00034        | 0.04949        | 0.00128        | 0.00512        |
| LYA01-08| 383     | 1.538| 0.00270        | 0.00152        | 0.00039        | 0.00003        | 0.05057        | 0.02503        | 0.00013        |
| **LYA-01 (Shuangshihyen volc. breccia)** | | | \textbf{2.4} | \textbf{0.5} | \textbf{2511} | \textbf{948} | \textbf{9.0} | \textbf{5.0} | \textbf{7.0} | \textbf{1.0} |
| LYA02-01| 298     | 0.326| 10.54172       | 0.22960        | 0.47100        | 0.00980        | 0.16235        | 0.00155        | 0.14692        |
| LYA02-02| 223     | 0.546| 5.21934        | 0.13165        | 0.33104        | 0.00750        | 0.11436        | 0.00126        | 0.10488        |
| LYA02-03| 88      | 0.571| 0.01095        | 0.00548        | 0.00112        | 0.00007        | 0.07109        | 0.03164        | 0.00048        |
| LYA02-04| 417     | 0.420| 7.99342        | 0.22458        | 0.39616        | 0.00808        | 0.14631        | 0.00193        | 0.11586        |
| LYA02-05| 415     | 0.862| 0.02300        | 0.00347        | 0.00108        | 0.00007        | 0.15374        | 0.01487        | 0.00040        |
| LYA02-06| 398     | 0.472| 9.72517        | 0.25577        | 0.43771        | 0.01041        | 0.16116        | 0.00185        | 0.12915        |
| LYA02-07| 85      | 0.538| 0.09938        | 0.00817        | 0.00953        | 0.00027        | 0.07561        | 0.00439        | 0.00313        |
| LYA02-08| 664     | 0.240| 9.72193        | 0.21833        | 0.44624        | 0.00965        | 0.15802        | 0.00156        | 0.13916        |
| LYA02-09| 205     | 0.478| 9.48144        | 0.20164        | 0.44993        | 0.00917        | 0.15285        | 0.00143        | 0.13876        |
| LYA02-10| 175     | 0.649| 10.53862       | 0.22754        | 0.46195        | 0.00961        | 0.16548        | 0.00157        | 0.14588        |
| LYA02-11| 53      | 1.111| 0.08076        | 0.02003        | 0.00870        | 0.00038        | 0.06731        | 0.01413        | 0.00265        |
| LYA02-12| 178     | 0.524| 7.38349        | 0.17961        | 0.39183        | 0.00815        | 0.13668        | 0.00146        | 0.12407        |
| LYA02-13| 836     | 0.338| 10.44693       | 0.25521        | 0.46611        | 0.00925        | 0.16258        | 0.00177        | 0.12420        |
| **LYA-02 (Tungching andesite)** | | | \textbf{2488} | \textbf{43} | \textbf{2480} | \textbf{15} | \textbf{2484} | \textbf{20} | \textbf{2771} | \textbf{76} |
| **Mean** | \textbf{2.5} | \textbf{0.2} | \textbf{221} | \textbf{831} | \textbf{3.0} | \textbf{2.0} | \textbf{2.6} | \textbf{0.2} | |
### Zircon U-Pb Age from Lutao and Lanyu

| U-Th-Pb ratios | Ages (Ma) |
|----------------|-----------|
| Spot | U (ppm) | Th/U | $^{207}$Pb/$^{235}$U ± 1 s | $^{206}$Pb/$^{238}$U ± 1 s | $^{207}$Pb/$^{206}$Pb ± 1 s | $^{208}$Pb/$^{232}$Th ± 1 s |
|------|---------|------|-----------------|-----------------|-----------------|-----------------|
| LYA-02 (Tungching andesite) |  |  |  |  |  |  |
| LYA02-15 | 1719 | 0.271 | 4.90480 | 0.13846 | 0.28258 | 0.00617 | 0.12589 | 0.00173 | 1604 | 31 |
| LYA02-16 | 1466 | 0.265 | 9.15173 | 0.27035 | 0.42475 | 0.01046 | 0.13630 | 0.00170 | 2282 | 47 |
| LYA02-17 | 1170 | 0.260 | 6.31083 | 0.26767 | 0.32766 | 0.00744 | 0.09329 | 0.00545 | 1827 | 36 |
| LYA02-18 | 193 | 0.990 | 0.2959 | 0.00364 | 0.0230 | 0.0009 | 0.08061 | 0.00173 | 14.8 | 0.6 |
| LYA02-19 | 238 | 0.429 | 8.26416 | 0.21362 | 0.41930 | 0.04280 | 0.13384 | 0.00742 | 2257 | 39 |

No magmatic zircon obtained.

| LYA-03 (Lungtouyen volc. breccia) |  |  |  |  |  |  |  |
|------|---------|------|-----------------|-----------------|-----------------|-----------------|-----------------|
| LYA03-01 | 1502 | 0.170 | 9.64836 | 0.27600 | 0.45019 | 0.01120 | 0.15547 | 0.00603 | 2396 | 50 |
| LYA03-02 | 753 | 0.893 | 0.00631 | 0.00162 | 0.00038 | 0.00003 | 0.11963 | 0.02238 | 2.5 | 0.2 |
| LYA03-03 | 845 | 1.163 | 0.00460 | 0.00253 | 0.00034 | 0.00004 | 0.09251 | 0.00221 | 96 | 3 |
| LYA03-04 | 347 | 0.725 | 0.00376 | 0.00167 | 0.00035 | 0.00003 | 0.09381 | 0.00834 | 2.3 | 0.2 |
| LYA03-05 | 221 | 1.053 | 0.13681 | 0.00463 | 0.02099 | 0.00046 | 0.13384 | 0.00742 | 134 | 3 |

| LYA-04 (Mantoushan andesite) |  |  |  |  |  |  |  |
|------|---------|------|-----------------|-----------------|-----------------|-----------------|-----------------|
| LYA04-01 | 2990 | 0.725 | 0.32313 | 0.00537 | 0.02290 | 0.00050 | 0.07385 | 0.00075 | 0.00947 | 146 | 3 |
| LYA04-02 | 475 | 0.694 | 0.00171 | 0.00142 | 0.00040 | 0.00003 | 0.03102 | 0.00019 | 2.5 | 0.2 |
| LYA04-03 | 3402 | 0.388 | 0.12940 | 0.00723 | 0.02037 | 0.00465 | 0.04608 | 0.00190 | 2.2 | 0.3 |
| LYA04-04 | 1126 | 0.752 | 0.15445 | 0.00366 | 0.02307 | 0.00049 | 0.04728 | 0.00081 | 2396 | 50 |
| LYA04-05 | 7220 | 0.571 | 0.19424 | 0.00436 | 0.02426 | 0.0052 | 0.04728 | 0.00081 | 14.8 | 0.6 |
| LYA04-06 | 9 | 0.422 | 15.82608 | 0.51143 | 0.49580 | 0.01200 | 0.13384 | 0.00742 | 2257 | 39 |
| LYA04-07 | 2242 | 1.449 | 0.18194 | 0.00423 | 0.02296 | 0.00049 | 0.09251 | 0.00221 | 146 | 3 |

| Mean $^{206}$Pb/$^{207}$U age = 2.35 ± 0.21 Ma (N = 4, MSWD = 0.31) |  |  |  |  |  |  |  |
|----------------|---------|------|-----------------|-----------------|-----------------|-----------------|-----------------|
| LYA-05 |  |  |  |  |  |  |  |

| Mean $^{206}$Pb/$^{238}$U age = 2.72 ± 0.23 Ma (N = 4, MSWD = 1.7) |  |  |  |  |  |  |  |
### Table 4. (Continued)

| Spot     | U (ppm) | Th/U | \(^{207}\text{Pb}/^{235}\text{U} \pm 1\ s | \(^{206}\text{Pb}/^{238}\text{U} \pm 1\ s | \(^{208}\text{Pb}/^{206}\text{Pb} \pm 1\ s | \(^{208}\text{Pb}/^{206}\text{Th} \pm 1\ s | \(^{206}\text{Pb}/^{238}\text{U} \pm 1\ s | \(^{207}\text{Pb}/^{235}\text{U} \pm 1\ s | \(^{208}\text{Pb}/^{206}\text{Pb} \pm 1\ s | \(^{208}\text{Pb}/^{206}\text{Th} \pm 1\ s |
|----------|---------|------|---------------------------------|---------------------------------|---------------------------------|---------------------------------|---------------------------------|---------------------------------|---------------------------------|---------------------------------|
| LYA-04-08 | 2036    | 2.041 | 0.00166 | 0.00033 | 0.00042 | 0.00001 | 0.02849 | 0.00506 | 0.00144 | 0.00001 |
| LYA-04-09 | 636     | 0.302 | 3.14970 | 0.10979 | 0.18774 | 0.00394 | 0.12940 | 0.00232 | 0.05341 | 0.00108 |
| LYA-04-10 | 749     | 0.588 | 0.26606 | 0.03973 | 0.02197 | 0.00775 | 0.08785 | 0.01082 | 0.00650 | 0.00021 |
| LYA-04-11 | 630     | 1.250 | 0.00447 | 0.00095 | 0.00050 | 0.00002 | 0.06442 | 0.01143 | 0.00018 | 0.00001 |
| LYA-04-12 | 767     | 1.515 | 0.00283 | 0.00027 | 0.00044 | 0.00001 | 0.04630 | 0.00348 | 0.00016 | 0.00001 |
| LYA-04-13 | 1224    | 2.439 | 0.00147 | 0.00043 | 0.00041 | 0.00001 | 0.02583 | 0.00699 | 0.00014 | 0.00001 |
| LYA-04-14 | 254     | 0.392 | 11.15109 | 0.26758 | 0.48408 | 0.00987 | 0.16708 | 0.00176 | 0.15624 | 0.00685 |
| LYA-04-15 | 154     | 0.267 | 9.99831 | 0.32799 | 0.45223 | 0.01143 | 0.16035 | 0.00218 | 0.12597 | 0.00312 |
| LYA-04-16 | 119     | 0.781 | 0.12273 | 0.00604 | 0.01655 | 0.00339 | 0.05380 | 0.00160 | 0.00534 | 0.00017 |
| LYA-04-17 | 386     | 1.408 | 0.16558 | 0.00668 | 0.02388 | 0.00661 | 0.05030 | 0.00104 | 0.00777 | 0.00032 |
| LYA-04-18 | 628     | 0.485 | 10.20987 | 0.23325 | 0.45472 | 0.00994 | 0.16287 | 0.00164 | 0.13936 | 0.00419 |

Mean \(^{206}\text{Pb}/^{238}\text{U} \text{age} = 2.72 \pm 0.23 \text{Ma (N = 4, MSWD = 1.7)}

### LYA-04 (Mantoushan andesite)

- **LYA-04-08**: 0.15349 Ma (N = 4, MSWD = 1.7)
- **LYA-04-09**: 0.15349 Ma (N = 4, MSWD = 1.7)
- **LYA-04-10**: 0.15349 Ma (N = 4, MSWD = 1.7)
- **LYA-04-11**: 0.15349 Ma (N = 4, MSWD = 1.7)
- **LYA-04-12**: 0.15349 Ma (N = 4, MSWD = 1.7)
- **LYA-04-13**: 0.15349 Ma (N = 4, MSWD = 1.7)
- **LYA-04-14**: 0.15349 Ma (N = 4, MSWD = 1.7)
- **LYA-04-15**: 0.15349 Ma (N = 4, MSWD = 1.7)
- **LYA-04-16**: 0.15349 Ma (N = 4, MSWD = 1.7)
- **LYA-04-17**: 0.15349 Ma (N = 4, MSWD = 1.7)
- **LYA-04-18**: 0.15349 Ma (N = 4, MSWD = 1.7)

| Ages (Ma) |
|-----------|
| 2.7 0.1  |
| 1109 21  |
| 140 5  |
| 3.2 0.1  |
| 2.9 0.1  |
| 2.6 0.1  |
| 2545 43  |
| 2405 51  |
| 106 2  |
| 152 4  |
| 2416 44  |

### LYA-05 (Shuangshihyen volc. breccia)

- **LYA-05-01**: 4.053 Ma (N = 4, MSWD = 1.7)
- **LYA-05-02**: 4.053 Ma (N = 4, MSWD = 1.7)
- **LYA-05-03**: 4.053 Ma (N = 4, MSWD = 1.7)
- **LYA-05-04**: 4.053 Ma (N = 4, MSWD = 1.7)
- **LYA-05-05**: 4.053 Ma (N = 4, MSWD = 1.7)
- **LYA-05-06**: 4.053 Ma (N = 4, MSWD = 1.7)
- **LYA-05-07**: 4.053 Ma (N = 4, MSWD = 1.7)
- **LYA-05-08**: 4.053 Ma (N = 4, MSWD = 1.7)
- **LYA-05-09**: 4.053 Ma (N = 4, MSWD = 1.7)
- **LYA-05-10**: 4.053 Ma (N = 4, MSWD = 1.7)

Mean \(^{206}\text{Pb}/^{238}\text{U} \text{age} = 4.053 \pm 0.23 \text{Ma (N = 4, MSWD = 1.7)}

### No magmatic zircon obtained.

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Table 4. (Continued)

| Spot  | U (ppm) | Th/U | U-Th-Pb ratios | Ages (Ma) |
|-------|---------|------|----------------|-----------|
|       |         |      | $^{207}$Pb/$^{206}$U ± 1 s | $^{208}$Pb/$^{206}$Pb ± 1 s | $^{206}$Pb/$^{207}$Pb ± 1 s | $^{208}$Pb/$^{206}$U ± 1 s |
| LYA05-11 | 47 | 0.962 | 6.79619 0.15661 0.38452 0.00834 0.12820 0.00129 0.12187 0.00324 | 2097 39 2073 18 2085 20 2324 58 |
| LYA05-12 | 1735 | 0.794 | 4.27736 0.10619 0.25747 0.00600 0.12050 0.00131 0.04875 0.00167 | 1477 31 1964 20 1689 20 962 32 |
| LYA05-13 | 12229 | 0.362 | 0.24444 0.02657 0.02685 0.00078 0.06604 0.00056 0.00820 0.00026 | 171 5 808 182 222 22 165 5 |
| LYA05-14 | 412 | 0.588 | 5.16138 0.26239 0.33255 0.00861 0.11257 0.00350 0.09594 0.00232 | 1851 42 1841 56 1846 43 1852 43 |
| LYA05-15 | 903 | 0.515 | 5.39324 0.13139 0.33324 0.00765 0.11740 0.00125 0.10560 0.00358 | 1854 37 1917 18 1884 21 2029 65 |
| LYA05-16 | 447 | 0.358 | 5.65044 0.13338 0.34636 0.00752 0.11834 0.00122 0.11446 0.00402 | 1917 36 1931 19 1924 20 2190 73 |
| LYA05-17 | 216 | 0.280 | 7.52905 0.17986 0.40129 0.00899 0.13609 0.00142 0.11998 0.00393 | 2175 41 2178 19 2176 21 2290 71 |
| LYA05-18 | 2985 | 0.239 | 0.16365 0.00871 0.02366 0.00061 0.05016 0.00069 0.00747 0.00016 | 151 4 202 76 154 8 150 3 |
| LYA05-19 | 1099 | 0.649 | 5.09080 0.12742 0.31437 0.00726 0.11746 0.00128 0.09809 0.00371 | 1762 36 1918 19 1835 21 1891 68 |
| LYA05-20 | 730 | 0.171 | 12.12637 0.33835 0.44149 0.01067 0.19923 0.00243 0.12308 0.00591 | 2357 48 2820 18 2614 26 2346 106 |
| LYA05-21 | 1143 | 0.538 | 5.60508 0.14068 0.30546 0.00703 0.13310 0.00146 0.08350 0.00322 | 1718 35 2139 20 1917 22 1621 60 |
| LYA05-22 | 510 | 0.510 | 5.85558 0.14007 0.35267 0.00782 0.12044 0.00126 0.11445 0.00402 | 1947 37 1963 20 1955 21 2190 73 |
| LYA05-23 | 603 | 0.855 | 5.90183 0.15290 0.35390 0.00821 0.12096 0.00137 0.10903 0.00463 | 1953 39 1970 21 1962 22 2092 84 |
| LYA05-24 | 234 | 2.381 | 9.01717 0.20938 0.43099 0.00887 0.15176 0.00154 0.13621 0.00504 | 2310 40 2366 17 2340 21 2581 90 |
| LYA05-25 | 2850 | 0.578 | 0.16082 0.01243 0.02385 0.00066 0.04890 0.00028 0.00755 0.00018 | 152 4 143 134 151 11 152 4 |
| LYA05-26 | 6057 | 0.917 | 0.16650 0.02254 0.02309 0.00073 0.05230 0.00057 0.00725 0.00017 | 1417 5 298 248 156 20 146 3 |
| LYA05-27 | 542 | 0.498 | 5.85397 0.12964 0.34869 0.00745 0.12178 0.00119 0.09134 0.00241 | 1928 36 1982 17 1954 19 1767 45 |
| LYA05-28 | 542 | 0.617 | 5.87062 0.13043 0.35294 0.00751 0.12065 0.00118 0.11654 0.00324 | 1949 36 1966 17 1957 19 2228 59 |
| LYA05-29 | 821 | 0.500 | 5.78967 0.14073 0.34926 0.00798 0.12024 0.00128 0.11531 0.00378 | 1931 38 1960 19 1945 21 2206 69 |
| LYA05-30 | 638 | 0.637 | 5.82614 0.14039 0.35167 0.00797 0.12017 0.00127 0.11419 0.00363 | 1943 38 1959 19 1950 21 2186 66 |
| LYA05-31 | 740 | 0.714 | 5.67511 0.13795 0.34728 0.00791 0.11853 0.00126 0.09954 0.00325 | 1922 38 1934 21 1928 21 1918 60 |
| LYA05-32 | 198 | 0.243 | 22.09059 0.49047 0.63626 0.01288 0.25189 0.00244 0.16413 0.00572 | 3174 51 3197 16 3188 22 3072 99 |
| LYA05-33 | 320 | 1.190 | 6.71672 0.15082 0.38182 0.00815 0.12760 0.00126 0.11941 0.00343 | 2085 38 2065 16 2075 20 2280 62 |

No magmatic zircon obtained.
| Spot | U (ppm) | Th/U | $^{207}$Pb/$^{235}$U ± 1 s | $^{206}$Pb/$^{238}$U ± 1 s | $^{206}$Pb/$^{235}$Th ± 1 s | Ages (Ma) |
|------|---------|------|--------------------------|--------------------------|--------------------------|-----------|
| LYA05-34 | 768.0649 | 5.95816 | 0.14018 | 0.35528 | 0.00784 | 0.12165 | 0.00125 | 0.11272 | 0.00359 | 2195.65 |
| LYA05-35 | 1468.0427 | 0.38218 | 0.09039 | 0.02561 | 0.00108 | 0.10821 | 0.02154 | 0.00742 | 0.00056 | 2170.19 |

No magmatic zircon obtained.

| LYS01-01 | 247.8000 | 0.00258 | 0.002210 | 0.00035 | 0.00003 | 0.05333 | 0.03934 | 0.00009 | 0.00002 | 2.3 0.2 |
| LYS01-02 | 459.1333 | 0.00617 | 0.00324 | 0.00047 | 0.00005 | 0.09529 | 0.04120 | 0.00014 | 0.00001 | 1960.37 |
| LYS01-03 | 204.7811 | 0.00270 | 0.00243 | 0.00037 | 0.00003 | 0.05336 | 0.04417 | 0.00017 | 0.00002 | 1981.19 |
| LYS01-04 | 147.7090 | 0.00350 | 0.00355 | 0.00032 | 0.00005 | 0.07826 | 0.06946 | 0.00010 | 0.00005 | 1970.20 |
| LYS01-05 | 366.7040 | 0.00088 | 0.00149 | 0.00042 | 0.00002 | 0.01515 | 0.02500 | 0.00019 | 0.00002 | 2159.65 |
| LYS01-06 | 139.7351 | 0.00724 | 0.00405 | 0.00044 | 0.00005 | 0.11931 | 0.05486 | 0.00014 | 0.00004 | 163 7 |
| LYS01-07 | 385.1010 | 0.00457 | 0.00133 | 0.00037 | 0.00002 | 0.09059 | 0.02206 | 0.00013 | 0.00001 | 1770.41 |
| LYS01-08 | 323.5811 | 0.00169 | 0.00154 | 0.00041 | 0.00002 | 0.02995 | 0.02598 | 0.00013 | 0.00002 | 1329.66 |
| LYS01-09 | 211.8401 | 0.00177 | 0.00232 | 0.00040 | 0.00003 | 0.03236 | 0.04024 | 0.00011 | 0.00002 | 149.11 |
| LYS01-10 | 256.9171 | 0.00395 | 0.00193 | 0.00042 | 0.00003 | 0.06778 | 0.02884 | 0.00026 | 0.00002 | 207 |
| LYS01-11 | 247.5951 | 0.00086 | 0.00201 | 0.00043 | 0.00003 | 0.01455 | 0.03310 | 0.00016 | 0.00003 | 2.0 |
| LYS01-12 | 177.8771 | 0.00100 | 0.00298 | 0.00037 | 0.00004 | 0.01961 | 0.05654 | 0.00015 | 0.00003 | 3.0 |
| LYS01-13 | 178.8201 | 0.00052 | 0.00295 | 0.00033 | 0.00004 | 0.01154 | 0.06421 | 0.00009 | 0.00003 | 0.00003 |
| LYS01-15 | 699.1923 | 0.00226 | 0.00070 | 0.00040 | 0.00002 | 0.04123 | 0.01095 | 0.00014 | 0.00001 | 0.00001 |
| LYS01-16 | 173.6291 | 0.00980 | 0.00335 | 0.00042 | 0.00005 | 0.16730 | 0.04113 | 0.00012 | 0.00001 | 0.00001 |
| LYS01-17 | 199.5381 | 7.77377 | 0.19484 | 0.40468 | 0.00916 | 0.13934 | 0.00152 | 0.11937 | 0.00458 | 2191.42 |
| LYS01-18 | 278.1010 | 0.00189 | 0.00175 | 0.00036 | 0.00002 | 0.03796 | 0.03326 | 0.00014 | 0.00001 | 2219.19 |
| LYS01-19 | 552.1333 | 0.00052 | 0.00086 | 0.00037 | 0.00002 | 0.00999 | 0.01604 | 0.00014 | 0.00001 | 2205.23 |
| LYS01-20 | 774.2041 | 0.00230 | 0.00073 | 0.00045 | 0.00002 | 0.03695 | 0.01027 | 0.00016 | 0.00001 | 2279.83 |

Mean $^{207}$Pb/$^{206}$U age = 2.63 ± 0.11 Ma (N = 25, MSWD = 4.1)
Table 4. (Continued)

| Spot       | U (ppm) | Th/U          | $^{207}\text{Pb}/^{235}\text{U}$ ± 1 s | $^{206}\text{Pb}/^{239}\text{U}$ ± 1 s | $^{206}\text{Pb}/^{206}\text{Pb}$ ± 1 s | $^{208}\text{Pb}/^{208}\text{Pb}$ ± 1 s | Ages (Ma) |
|------------|---------|---------------|----------------------------------------|----------------------------------------|----------------------------------------|----------------------------------------|------------|
| LYS01-21   | 438     | 0.578         | 0.00120                                | 0.000110                               | 0.000045                               | 0.000022                               | 2.9        |
| LYS01-22   | 114     | 0.581         | 0.00369                                | 0.00437                                | 0.00337                                | 0.00005                                | 2.4        |
| LYS01-23   | 172     | 0.680         | 0.00114                                | 0.00274                                | 0.00038                                | 0.00003                               | 2.4        |
| LYS01-24   | 197     | 0.855         | 0.00076                                | 0.00257                                | 0.00037                                | 0.00003                               | 2.4        |
| LYS01-25   | 735     | 2.381         | 0.00286                                | 0.00085                                | 0.00049                                | 0.00002                               | 3.2        |
| LYS01-26   | 610     | 1.538         | 0.00057                                | 0.00090                                | 0.00038                                | 0.00002                               | 2.4        |
| LYS01-27   | 367     | 0.990         | 0.00045                                | 0.00217                                | 0.00045                                | 0.00022                               | 2.9        |

Mean $^{206}\text{Pb}/^{207}\text{U}$ age = 2.63 ± 0.11 Ma (N = 25, MSWD = 4.1)

| Spot       | U (ppm) | Th/U          | $^{207}\text{Pb}/^{235}\text{U}$ ± 1 s | $^{206}\text{Pb}/^{239}\text{U}$ ± 1 s | $^{206}\text{Pb}/^{206}\text{Pb}$ ± 1 s | Ages (Ma) |
|------------|---------|---------------|----------------------------------------|----------------------------------------|----------------------------------------|------------|
| LYS02-01   | 206     | 0.472         | 10.86816                               | 0.27436                                | 0.47084                                | 0.01776    | 2487       |
| LYS02-02   | 136     | 0.413         | 11.14621                               | 0.25324                                | 0.48011                                | 0.01025    | 2579       |
| LYS02-03   | 148     | 0.500         | 11.28146                               | 0.27502                                | 0.49203                                | 0.01102    | 2528       |
| LYS02-04   | 1067    | 0.508         | 9.41149                                | 0.07240                                | 0.08775                                | 0.00213    | 2399       |
| LYS02-05   | 296     | 0.413         | 9.79159                                | 0.33232                                | 0.43535                                | 0.00997    | 2300       |
| LYS02-06   | 189     | 0.332         | 10.72898                               | 0.24559                                | 0.47363                                | 0.00977    | 2399       |
| LYS02-07   | 148     | 0.488         | 11.26340                               | 0.25337                                | 0.48395                                | 0.01045    | 2399       |
| LYS02-08   | 309     | 0.617         | 0.00795                                | 0.00238                                | 0.00066                                | 0.00004    | 2399       |
| LYS02-09   | 195     | 0.508         | 11.50657                               | 0.28520                                | 0.49019                                | 0.01128    | 2399       |
| LYS02-10   | 176     | 0.549         | 11.25843                               | 0.24558                                | 0.48213                                | 0.01010    | 2399       |
| LYS02-11   | 179     | 0.581         | 11.41398                               | 0.25216                                | 0.48703                                | 0.01033    | 2399       |
| LYS02-12   | 124     | 0.510         | 11.07507                               | 0.25785                                | 0.47674                                | 0.00999    | 2399       |
| LYS02-13   | 127     | 0.256         | 10.89932                               | 0.24897                                | 0.47458                                | 0.01006    | 2399       |
| LYS02-14   | 256     | 1.163         | 0.00290                                | 0.00237                                | 0.00040                                | 0.00003    | 2399       |

Mean $^{206}\text{Pb}/^{207}\text{U}$ age = 3.05 ± 0.27 Ma (N = 9, MSWD = 3.0)
Table 4. (Continued)

| Spot     | U (ppm) | Th/U | $^{207}$Pb/$^{235}$U | ± 1 s  | $^{206}$Pb/$^{238}$U | ± 1 s  | $^{206}$Pb/$^{208}$Pb | ± 1 s  | $^{208}$Pb/$^{232}$Th | ± 1 s  | Ages (Ma) |
|----------|---------|------|----------------------|--------|----------------------|--------|----------------------|--------|----------------------|--------|-----------|
| LYS02-15 | 179     | 0.336 | 10.44953             | 0.26864 | 0.46215              | 0.01008 | 0.16401              | 0.00185 | 0.14398              | 0.00653 | 2449      |
| LYS02-16 | 187     | 0.472 | 11.29293             | 0.27450 | 0.48346              | 0.01084 | 0.16944              | 0.00180 | 0.13539              | 0.00453 | 2542      |
| LYS02-17 | 192     | 0.312 | 8.68680              | 0.26528 | 0.40928              | 0.00988 | 0.15717              | 0.00210 | 0.11146              | 0.00593 | 2212      |
| LYS02-18 | 839     | 0.267 | 5.07750              | 0.11485 | 0.32199              | 0.00689 | 0.11438              | 0.00113 | 0.09625              | 0.00286 | 1799      |
| LYS02-19 | 151     | 0.323 | 9.63892              | 0.32887 | 0.44754              | 0.00978 | 0.15621              | 0.00284 | 0.12498              | 0.00269 | 2384      |
| LYS02-20 | 152     | 0.385 | 10.86052             | 0.26876 | 0.46610              | 0.00994 | 0.16903              | 0.00183 | 0.14092              | 0.00605 | 2466      |
| LYS02-21 | 1217    | 0.383 | 5.48661              | 0.14855 | 0.34211              | 0.00776 | 0.11633              | 0.00139 | 0.09409              | 0.00460 | 1897      |
| LYS02-22 | 100     | 0.264 | 9.53047              | 0.23685 | 0.44626              | 0.00924 | 0.15494              | 0.00170 | 0.13521              | 0.00628 | 2379      |
| LYS02-23 | 163     | 0.758 | 0.00341              | 0.00373 | 0.00060              | 0.00060 | 0.00101              | 0.00180 | 0.01601              | 0.00304 | 3.9       |
| LYS02-24 | 60      | 0.346 | 11.29068             | 0.28195 | 0.48877              | 0.01125 | 0.16759              | 0.00183 | 0.14064              | 0.00450 | 2565      |
| LYS02-25 | 611     | 0.775 | 8.27838              | 0.19271 | 0.42007              | 0.00934 | 0.14298              | 0.00146 | 0.12621              | 0.00366 | 2261      |
| LYS02-26 | 250     | 0.364 | 10.39010             | 0.23836 | 0.46033              | 0.00974 | 0.16372              | 0.00164 | 0.14488              | 0.00498 | 2441      |
| LYS02-27 | 228     | 0.319 | 10.97946             | 0.25287 | 0.47341              | 0.01014 | 0.16823              | 0.00169 | 0.14133              | 0.00462 | 2498      |
| LYS02-28 | 210     | 0.794 | 0.10726              | 0.00763 | 0.00466              | 0.00019 | 0.16677              | 0.00646 | 0.00102              | 0.00007 | 30        |
| LYS02-29 | 278     | 1.064 | 0.00442              | 0.00222 | 0.00046              | 0.00003 | 0.06908              | 0.03070 | 0.00011              | 0.00002 | 3.0       |
| LYS02-30 | 691     | 0.820 | 1.18263              | 0.02784 | 0.12726              | 0.00280 | 0.06741              | 0.00069 | 0.04034              | 0.00122 | 772       |
| LYS02-31 | 340     | 0.621 | 0.00130              | 0.00154 | 0.00055              | 0.00003 | 0.01716              | 0.01949 | 0.00020              | 0.00002 | 3.5       |
| LYS02-32 | 160     | 0.610 | 0.00527              | 0.00379 | 0.00059              | 0.00005 | 0.06463              | 0.04162 | 0.00033              | 0.00005 | 3.8       |
| LYS02-33 | 164     | 0.541 | 11.19276             | 0.26085 | 0.47841              | 0.01005 | 0.16969              | 0.00172 | 0.14311              | 0.00522 | 2520      |
| LYS02-34 | 156     | 0.437 | 11.00019             | 0.25829 | 0.47675              | 0.01047 | 0.16736              | 0.00172 | 0.13838              | 0.00450 | 2513      |
| LYS02-35 | 151     | 0.472 | 11.12420             | 0.25328 | 0.48130              | 0.01030 | 0.16764              | 0.00167 | 0.14178              | 0.00443 | 2533      |
| LYS02-36 | 188     | 0.338 | 10.08953             | 0.23396 | 0.45833              | 0.00990 | 0.15967              | 0.00162 | 0.14365              | 0.00470 | 2432      |
| LYS02-37 | 208     | 0.465 | 10.66565             | 0.29848 | 0.46397              | 0.01108 | 0.16675              | 0.00205 | 0.13527              | 0.00668 | 2457      |

Mean $^{206}$Pb/$^{238}$U age = 3.05 ± 0.27 Ma (N = 9, MSWD = 3.0)
Table 4. (Continued)

| Spot   | U (ppm) | Th/U | $^{206}\text{Pb}/^{238}\text{U}$ | $^{206}\text{Pb}/^{238}\text{U}$ ± 1 s | $^{206}\text{Pb}/^{235}\text{U}$ | $^{207}\text{Pb}/^{206}\text{Pb}$ | $^{207}\text{Pb}/^{206}\text{Pb}$ ± 1 s | $^{208}\text{Pb}/^{232}\text{Th}$ | $^{208}\text{Pb}/^{232}\text{Th}$ ± 1 s | Ages (Ma) |
|--------|---------|------|---------------------------------|-------------------------------------|-------------------------------|-----------------------------------|-------------------------------------|-----------------------------------|-----------------------------------|-----------|
| LYS02-38 | 206.0 | 0.552 | 11.02516 | 0.28487 | 0.48052 | 0.01103 | 0.16642 | 0.00187 | 0.13925 | 0.00588 | 2530 | 48.0 | 2522 | 18.0 | 2525 | 24.0 | 2635 | 104.0 |
| LYS02-39 | 355.0 | 0.220 | 8.78107 | 0.19629 | 0.42019 | 0.00828 | 0.15157 | 0.00149 | 0.11769 | 0.00233 | 2261 | 38.0 | 2364 | 17.0 | 2316 | 20.0 | 2249 | 42.0 |
| LYS02-40 | 181.0 | 0.935 | 0.3939 | 0.00429 | 0.00183 | 0.00009 | 0.15605 | 0.01063 | 0.00040 | 0.00004 | 11.8 | 0.6 | 2413 | 106.0 | 39.0 | 4.0 | 8.1 | 0.8 |
| LYS02-41 | 231.0 | 0.481 | 9.95284 | 0.33737 | 0.45275 | 0.01140 | 0.15944 | 0.00236 | 0.12619 | 0.03111 | 2407 | 51.0 | 2450 | 26.0 | 2430 | 31.0 | 2402 | 56.0 |
| LYS02-42 | 460.0 | 0.870 | 8.78192 | 0.19761 | 0.43585 | 0.00946 | 0.14615 | 0.00145 | 0.12801 | 0.00343 | 2332 | 42.0 | 2301 | 16.0 | 2316 | 21.0 | 2435 | 61.0 |
| LYS02-43 | 126.0 | 0.730 | 0.06016 | 0.00700 | 0.00297 | 0.00015 | 0.14710 | 0.01092 | 0.00100 | 0.00009 | 19.1 | 1.0 | 2312 | 123.0 | 59.0 | 7.0 | 20.0 | 2.0 |
| LYS02-44 | 190.0 | 0.526 | 10.96663 | 0.25649 | 0.47622 | 0.01061 | 0.16706 | 0.00172 | 0.13766 | 0.00413 | 2511 | 46.0 | 2528 | 16.0 | 2520 | 22.0 | 2607 | 73.0 |
| LYS02-45 | 201.0 | 1.053 | 0.12879 | 0.00840 | 0.00515 | 0.00020 | 0.18135 | 0.00629 | 0.00081 | 0.00006 | 33.0 | 1.0 | 2665 | 59.0 | 123.0 | 8.0 | 16.0 | 1.0 |
| LYS02-46 | 170.0 | 0.926 | 0.00141 | 0.00404 | 0.00044 | 0.00006 | 0.02310 | 0.00633 | 0.00016 | 0.00003 | 2.8 | 0.4 | -604 | 1587.0 | 1.0 | 4.0 | 3.2 | 0.6 |
| LYS02-47 | 158.0 | 0.498 | 11.72639 | 0.27564 | 0.48626 | 0.01081 | 0.17493 | 0.00180 | 0.15629 | 0.00491 | 2554 | 47.0 | 2605 | 16.0 | 2583 | 22.0 | 2935 | 86.0 |
| LYS02-48 | 191.0 | 0.855 | 0.1058 | 0.00361 | 0.00075 | 0.00006 | 0.10276 | 0.02790 | 0.00024 | 0.00003 | 4.8 | 0.4 | 1675 | 544.0 | 11.0 | 4.0 | 4.9 | 0.6 |
| LYS02-49 | 160.0 | 0.741 | 0.00239 | 0.00307 | 0.00045 | 0.00004 | 0.03823 | 0.04607 | 0.00015 | 0.00003 | 2.9 | 0.3 | -395 | 1230.0 | 2.0 | 3.0 | 3.0 | 0.6 |
| LYS02-50 | 399.0 | 0.775 | 0.00336 | 0.00132 | 0.00046 | 0.00002 | 0.05295 | 0.01876 | 0.00016 | 0.00001 | 3.0 | 0.1 | 327 | 645.0 | 3.0 | 1.0 | 3.2 | 0.2 |
| LYS02-51 | 831.0 | 0.704 | 1.34636 | 0.03356 | 0.13495 | 0.00297 | 0.07237 | 0.00797 | 0.04388 | 0.00172 | 816 | 17.0 | 996 | 23.0 | 866 | 15.0 | 862 | 33.0 |
| LYS02-52 | 373.0 | 0.469 | 0.00736 | 0.00192 | 0.00084 | 0.00004 | 0.06337 | 0.01388 | 0.00036 | 0.00004 | 5.4 | 0.3 | 721 | 453.0 | 7.0 | 2.0 | 7.3 | 0.8 |
| LYS02-53 | 199.0 | 1.053 | 0.00882 | 0.00300 | 0.00041 | 0.00004 | 0.15442 | 0.03951 | 0.00013 | 0.00002 | 2.6 | 0.3 | 2395 | 497.0 | 9.0 | 3.0 | 2.6 | 0.4 |

Mean $^{206}\text{Pb}/^{238}\text{U}$ age = 3.05 ± 0.27 Ma (N = 9, MSWD = 3.0)
magmatic activities of the islet. The remaining grains are mostly of Paleoproterozoic ages (Table 4). It is interesting to note that age data have never been reported by any of previous studies from this volcanic unit, whose magmatic age can be inferred by a detrital mean age of 2.63 ± 0.11 Ma obtained from a river sand sample LYS-01 (see below).

4.2.3 Mantoushan Andesite

Sample LYA-04 from this unit is a basaltic andesite (Table 1) from which eighteen grains of zircon were obtained for age determination that yielded a weighted mean $^{206}\text{Pb}/^{238}\text{U}$ age of 2.72 ± 0.23 Ma (n = 4; MSWD = 1.7; Fig. 10c). A fifth grain, with $^{206}\text{Pb}/^{238}\text{U}$ age dated at 3.2 ± 0.1 Ma (Table 4), is interpreted as a xenocryst and thus excluded from the mean age calculation. This mean age is slightly older than that obtained from the Lungtouyen breccia and the zircon fission-track ages of 2.4 - 1.8 Ma (Yang et al. 1995), but apparently younger than two Ar-Ar ages of 6.6 ± 0.1 and 3.5 ± 0.1 Ma (Lo et al. 1994) and the K-Ar ages of 25.1 - 3.8 Ma (Richard et al. 1986). Other thirteen grains are inherited zircons (Table 4), including eight of Cretaceous ages and the others of Proterozoic to Neoarchean ages.

4.2.4 Shuangshihyen Volcanic Breccia

Two samples were collected from this volcanic unit, i.e., (1) LYA-01 that is a basalt and (2) LYA-05, a basaltic andesite (Table 1). Only eight grains of zircon were available for age determination and three of them yielded a weighted mean $^{206}\text{Pb}/^{238}\text{U}$ age of 2.50 ± 0.17 Ma (n = 3; MSWD = 0.1; Fig. 10a) can be interpreted as the magma crystallization age that is apparently younger than the K-Ar ages of 5.5 - 3.9 Ma (Richard et al. 1986). The remaining five grains are of Cretaceous and Paleoproterozoic ages (Table 4). Sample LYA-05, by contrast, has rather more abundant zircons but thirty-five grains selected for U-Pb age determination did not yield any young magmatic age at all (Table 4). Therefore, all these zircons are xenocrysts of inherited origin, including seven grains of Jurassic ages, twenty-six of Proterozoic ages, and remaining two of Archean ages.

4.2.5 Sands

The samples from two areas close-by (Fig. 1b) show significant variations in the detrital zircon age distribution (Table 4). Sample LYS-01 (river sands) holds overwhelmingly

Fig. 10. $^{206}\text{Pb}/^{238}\text{U}$ age spectra and weighted mean values of Lanyu volcanic rocks (a to c) and sands (d and e). The numerical value (N) denotes the number of zircon grains analyzed and the analytical error bars are 2σ.
young zircons that yielded a weighted mean $^{206}$Pb/$^{238}$U age of 2.63 ± 0.11 Ma (n = 25; MSWD = 4.1; Fig. 10d), except for a single Paleoproterozoic grain. As above-mentioned, this mean age may indicate or approximate to the age of the volcanic unit “Tungching andesite”, the most likely source provenance of river sands (Fig. 1b). By contrast, sample LYS-02 (beach sands) has less young zircons but much more old zircons (Table 4), with the former yielding a weighted mean $^{206}$Pb/$^{238}$U age of 3.05 ± 0.27 Ma (n = 9; MSWD = 3.0; Fig. 10e), which is slightly older than, but still broadly coeval to, the mean age of sample LYS-01. The remaining forty-four grains are older zircons that show a very wide range of U-Pb ages from Pliocene (e.g., 4.3, 4.8, and 5.4 Ma) to Neoarchean (~2.5 Ga, n = 10).

5. DISCUSSION

5.1 Significance of Zircon U-Pb Ages from Lutao

Magmatic zircons of seven samples from the four volcanic units of Lutao yielded the following weighted mean $^{206}$Pb/$^{238}$U age results: (1) the Ameishan volcanic breccia: 1.54 ± 0.12 and 1.44 ± 0.06 Ma, (2) the Niutzushan andesite: 1.28 ± 0.06 Ma, (3) the Kungkuan andesite: 1.36 ± 0.05, 1.25 ± 0.05, and 1.24 ± 0.04 Ma, and (4) the Huoshaoshan andesite: 1.24 ± 0.08 Ma (Table 1 and Fig. 8). Collectively, a total of 190 grains of magmatic zircons, out of 222 grains dated from the seven samples, yielded an overall mean $^{206}$Pb/$^{238}$U age of 1.31 ± 0.03 Ma (MSWD = 2.6; Fig. 11a).

This is slightly older than, yet still in broad accord with, another overall mean $^{206}$Pb/$^{238}$U age of 1.23 ± 0.03 Ma (n = 103, MSWD = 1.9) given by the young group of detrital zircons from the three samples of sands (Fig. 11b). These age data suggest that in Lutao all the four volcanic units are Quaternary sequences erupting in a rather short time period from ~1.54 to ~1.24 Ma. From an overall point of view, the age data signify that the volcanism in Lutao is characterized with a major stage of eruption occurring at ~1.3 Ma.

In addition, our zircon age data suggest that Lutao may have had a slightly earlier albeit subordinate arc magma activity ~2.4 - 2.0 Ma (n = 4), overlapping somewhat with...
the major eruption in Lanyu that took place at ~2.6 Ma (see below). The remaining thirty-five grains are either inherited or detrital zircons, from volcanics and sands, respectively (Table 3 and Fig. 11), which show much older U-Pb ages from 52 to 2703 Ma and have little to do with the young volcanism in the northern Luzon arc; their geologic significance will be discussed in a later section.

5.2 Significance of Zircon U-Pb Ages from Lanyu

Limited grains of magmatic zircons from the five Lanyu volcanic samples yielded the following weighted mean $^{206}\text{Pb}/^{238}\text{U}$ age results (Table 1 and Fig. 10): (1) the Lungtouyen volcanic breccia: 2.35 ± 0.21 Ma (n = 4), (2) the Tungching andesite: no magmatic zircons, with an inferred age of 2.63 ± 0.11 Ma from detrital zircons, (3) the Mantoushan andesite: 2.72 ± 0.23 Ma (n = 4), and (4) the Shuangshihyen volcanic breccia: 2.50 ± 0.17 Ma (n = 3). Collectively, a total of only eleven grains of magmatic zircons, out of 85 grains dated from the five samples, yielded an overall mean $^{206}\text{Pb}/^{238}\text{U}$ age of 2.61 ± 0.13 Ma (MSWD = 1.8; Fig. 12a). This mean age coincides with another mean $^{206}\text{Pb}/^{238}\text{U}$ age of 2.69 ± 0.11 Ma (n = 34, MSWD = 4.7) obtained by the young group of detrital zircons from the two sands (Fig. 12b). Given the small number of magmatic grains dated, leading to the large 2-sigma errors of individual sample, we use only the overall statistics to conclude that the volcanism in Lanyu is characterized with a major stage of eruption at ~2.6 Ma.

Nevertheless, there are older stages of arc magmatism in Lanyu, as delineated by zircon ages of ~3 - 3.9 (n = 4), 4.3 - 5.4 (n = 3), ~7 (n = 2), ~12 and ~15 Ma (Table 4). This line of age information echoes the evolutionary model proposed for the northern Luzon arc system (Lai and Song 2013) wherein each volcano group from the Coastal Range to Lutao has its own life span with concomitant changes in lithofacies and geochemical characteristics. The Miocene stages, if existed in Lanyu, correspond to our unpublished zircon U-Pb age results from the Coastal Range, where a cluster of inherited zircons dated ~15 Ma from the Chimei igneous complex and zircon mean ages of volcanic rocks from ~9.2 to 6.5 Ma have been observed (Shao et al. 2011, 2012). In addition, the youngest zircon U-Pb age obtained so far is ~4.5 Ma, recorded by several grains of magmatic zircons from the Shihtiping white tuff (Shao et al. unpubl. data).

![Fig. 12. Collective plots of zircon U-Pb ages from Lanyu (a) volcanic rocks and (b) sands. The numerical value (N) denotes the number of zircon grains analyzed and the analytical error bars are 2σ.](image-url)
5.3 Discrepancies with Ages from Other Methods

In comparison with our zircon U-Pb isotope data, which suggest ~1.3 Ma in Lutao and ~2.6 Ma in Lanyu to be the main eruption ages, discrepancies are often observed in volcanic ages obtained by other methods. The available K-Ar ages, for instance, are 4.3 - 1.8 Ma (five samples) from Lutao and 25.1 - 3.7 Ma (thirteen samples) from Lanyu (Richard et al. 1986). They appear to be longer lived and somewhat older than the Ar-Ar ages, i.e., 1.5 ± 0.2 and 1.4 ± 0.1 Ma (two samples) from Lutao and 6.6 ± 0.1 and 3.5 ± 0.1 Ma (two samples) from Lanyu (Lo et al. 1994). As discussed by Yang et al. (1995), these age data may have been affected in various amounts by the excess radiogenic Ar inherited from xenocrystic hornblendes or biotites that formed in older volcanic eruptions. Related features of isotopic disequilibrium had also been reported for some phenocrysts, or in fact xenocrysts, in volcanic rocks from Lutao and Lanyu (Lan et al. 1986; Chen 1989). We note that more detailed comparison between the age data obtained by different methods is uneasy, or unrealistic, because the samples were collected by different investigations and thus from different outcrops.

Fission-track ages of zircons, i.e., 1.7 - 0.5 Ma (eleven samples) from Lutao and 3.3 - 1.4 Ma (seven samples) from Lanyu (Yang et al. 1995) appear to be broadly corresponding although in a more scattered fashion, with our zircon U-Pb age results. The reasons may essentially be twofold, due to the occurrence of old inherited zircons and post-eruptional thermal events. Much older fission-track ages were indeed observed and explained as the result of partial annealing of inherited or xenocrystic zircons (Yang et al. 1995). Fission-track ages that are younger than the major eruption ages defined by our zircon U-Pb ages, therefore, are explained as having been affected more or less by later thermal events and bear insignificant geologic meaning.

5.4 Higher U in Younger Magmatic Zircons

The young magmatic zircons from both Lutao and Lanyu show high U concentrations (Fig. 13), i.e., (1) Lutao, with U ranging from 175 - 4979 ppm (Table 3) that yields an average of 909 ppm (n = 293), and (2) Lanyu, ranging from 114 - 2036 ppm (Table 4) and an average of 417 ppm (n = 41) both of which are obviously higher than the U concentrations of magmatic zircons from the Coastal Range (Shao et al. 2011, 2012). The latter, ranging largely from ~20 to 200 ppm (Fig. 13), correspond to zircons that crystallize from arc magmas in the intra-oceanic subduction zone (Hanchar and Hoskin 2003). Taking together, the data reveal that U concentrations of magmatic zircons in the northern Luzon arc increase through time (Fig. 13), with a significant jump occurring at ~5 Ma, when the arc system began.
colliding with the Eurasian continental margin (cf. Teng 1990).

Similarly, secular changes in whole-rock geochemical and isotopic compositions of the northern Luzon arc volcanics have been documented by some previous studies (e.g., Chen et al. 1990; Yang 1992; Yang et al. 1995; Lai and Song 2013). A general consensus reached by most workers is that, in response to the arc-continent collision of Taiwan, the northern Luzon arc magmatism involved an increasing amount of subducted terrigenous sediments in the past ~5 Ma (see Lai and Song 2013, and references therein). More specifically, as first postulated by Chen et al. (1990), the sediment subduction resulted in enrichment or “source contamination” in the mantle wedge of the northern Luzon arc system. Subsequent melting of such enriched mantle source gave rise to the volcanic activities in Lanyu (~2.6 Ma) and then Lutao (~1.3 Ma) that show increasing degrees of enrichment in certain geochemical and isotopic compositions. Our zircon uranium concentration data, therefore, support the whole-rock argument and is interpreted as a useful signal of the enrichment event.

5.5 Significance of Abundant Old Zircons

As above-described, various amounts of old inherited zircons are observed from almost every volcanic sample from both Lutao and Lanyu. Putting together, these include 25 out of a total of 222 grains (~11%) from the Lutao and 70 out of 85 grains (~82%) from Lanyu. In the former, their ages are between 52 and 2703 Ma, including a large group of Paleoproterozoic zircons (Fig. 11). In the latter, the ages span from 56 to 3197 Ma, with three main clusters at ~150 Ma and ~1.9 and ~2.5 Ga (Fig. 12). Similar results are observed in the river and beach sands, despite less abundance than that of the volcanic samples. Older detrital zircons include 10 out of 114 grains analyzed (~9%) from Lutao and 46 out of 80 grains (~58%) from Lanyu (Tables 3 and 4). Abundant inherited zircons of Yanshanian/Indosinian and older ages have also been obtained for volcanic samples from the Chimei complex and elsewhere along the Coastal Range (Shao et al. 2011, 2012). We therefore argue this to be a general feature for the entire northern Luzon arc that, as addressed by Shao et al. (2011, 2012), is an intra-oceanic arc terrane containing or underlain with a “hidden” continental fragment. Such a continental fragment was rifted from the South China Block during opening of the South China Sea and accreted to the western margin of the Philippine Sea, thus initiating eastward subduction of the South China Sea plate under the Philippine Sea plate to form the northern Luzon arc system. Consequently, magmas derived from the mantle wedge of the Luzon arc picked up the old zircons from the accreted continental fragment through crustal assimilation during magma ascent or within the magma chamber. A detailed petrogenetic model, however, is beyond the scope of this paper and will be presented as a separate article in preparation for publication.

6. CONCLUDING REMARKS

The present study leads to the following major conclusions:

(1) The zircon U-Pb age data indicate that volcanic rocks exposed in Lutao were emplaced in the Quaternary during a short period of time (~0.3 m.y.) from ~1.54 to ~1.24 Ma, with the major eruption occurring at ~1.3 Ma. In addition, three slightly older zircon grains, dated at ~2.4 - 2.0 Ma, are observed.

(2) The volcanic rocks exposed in Lanyu were emplaced at ~2.6 Ma. Yet, inherited and detrital zircon data suggest that arc magmatism in the islet started earlier and may have been active from the middle Miocene to Pliocene.

(3) Magmatic zircons from both islets contain U concentrations apparently higher than those from the Coastal Range, consistent with the whole-rock geochemical argument for the northern Luzon arc magma generation with an increasing amount of subducted sediment in the past ~5 Ma.

(4) Volcanic rocks from both islets contain various amounts of old inherited zircons, ~11% in Lutao and up to ~82% in Lanyu, which together with detrital zircons from river/beach sands show main age peaks at ~150 Ma and ~1.9 and ~2.5 Ga. These data lend further support to the notion for the existence of a “hidden” continental fragment beneath the northern Luzon magmatic arc.

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