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

Wen-Yu Shao, Sun-Lin Chung *, and Wen-Shan Chen

Department of Geosciences, National Taiwan University, Taipei, Taiwan

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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 $^{206}Pb/^{238}U$ age of 1.31 ± 0.03 Ma (n = 190, MSWD = 2.6). This is slightly older than, or broadly coincident with, a mean $^{206}Pb/^{238}U$ age of 1.23 ± 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 $^{206}Pb/^{238}U$ age of 2.61 ± 0.13 Ma (n = 11, MSWD = 1.8). This accords with a mean $^{206}Pb/^{238}U$ age of 2.69 ± 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

* *Corresponding author*
E-mail: sunlin@ntu.edu.tw

(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 Huoshaoshan 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

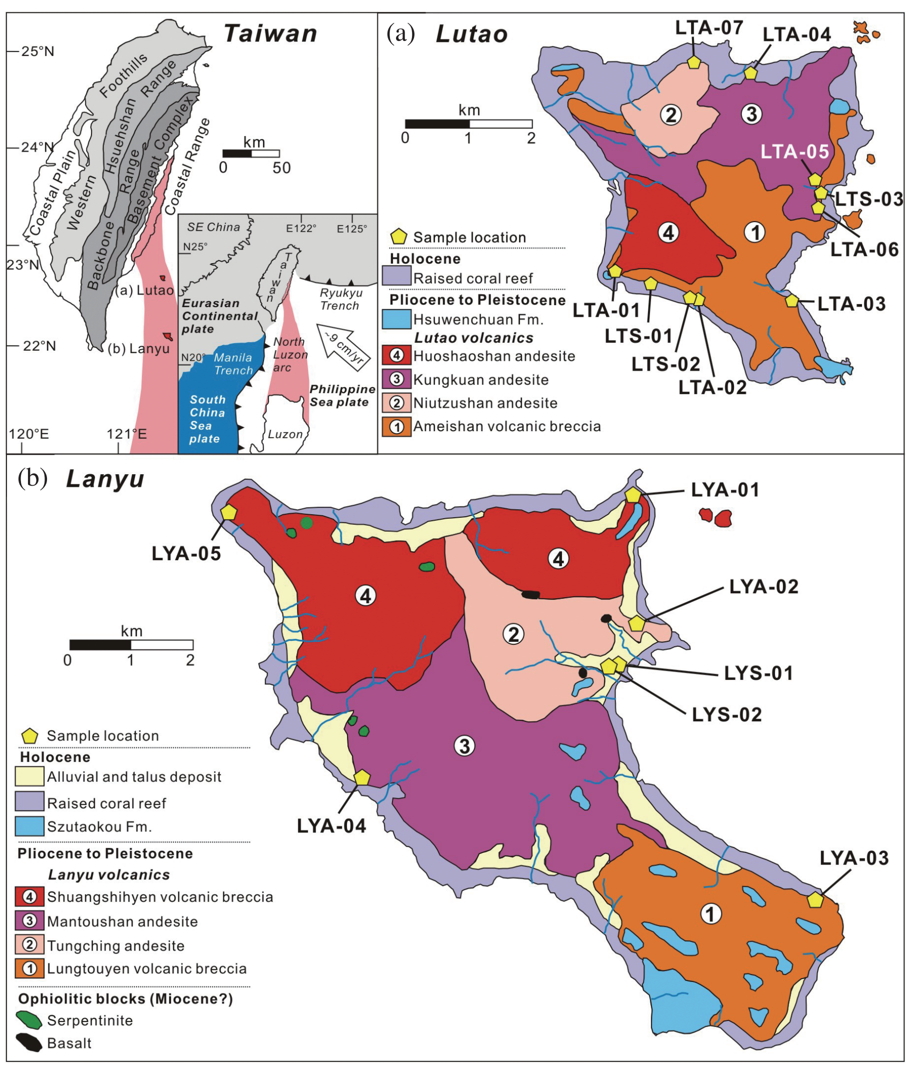

Fig. 1. A simplified tectonic framework of Taiwan and the Luzon arc system. Geologic maps of (a) Lutao (after Chen et al. 1994a) and (b) Lanyu (after Chen et al. 1994b). Also shown are sample localities.

Table 1. Summary of zircon U-Pb ages and relevant information of samples from Lutao and Lanyu.

Lutao								
sample	**longitude**	**latitude**	**volcanic unit**	**occurrence**	**rock type**	**SiO_2 (wt.%)***	**age ± 2σ (Ma)**	**remarks**
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''	Niutzushan 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								
sample	**longitude**	**latitude**	**volcanic unit**	**occurrence**	**rock type**	**SiO2 (wt.%)***	**age ± 2σ (Ma)**	**remarks**
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).*

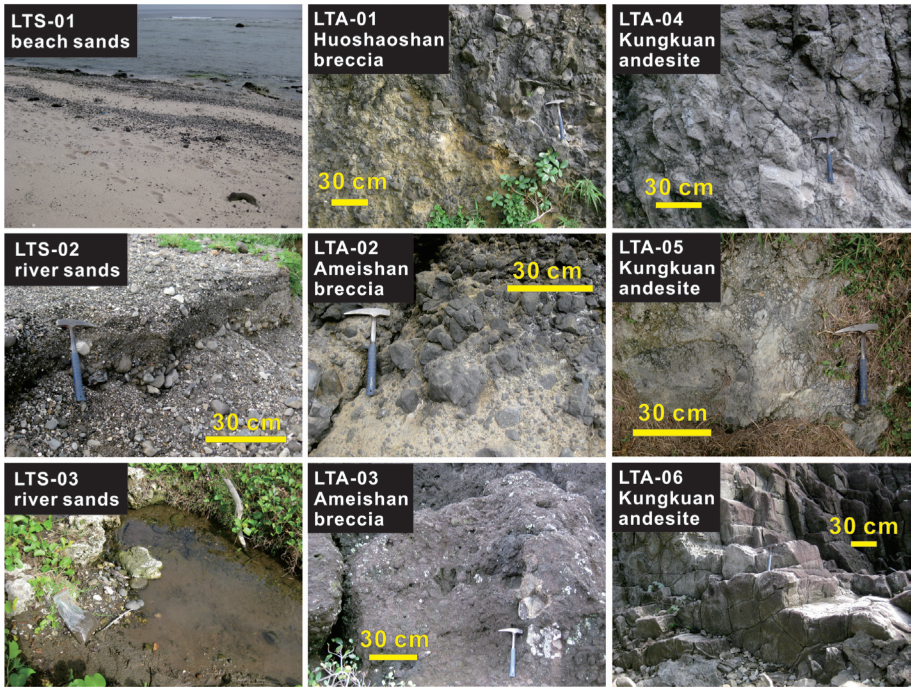

Fig. 2. Field occurrence photos of the Lutao samples.

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

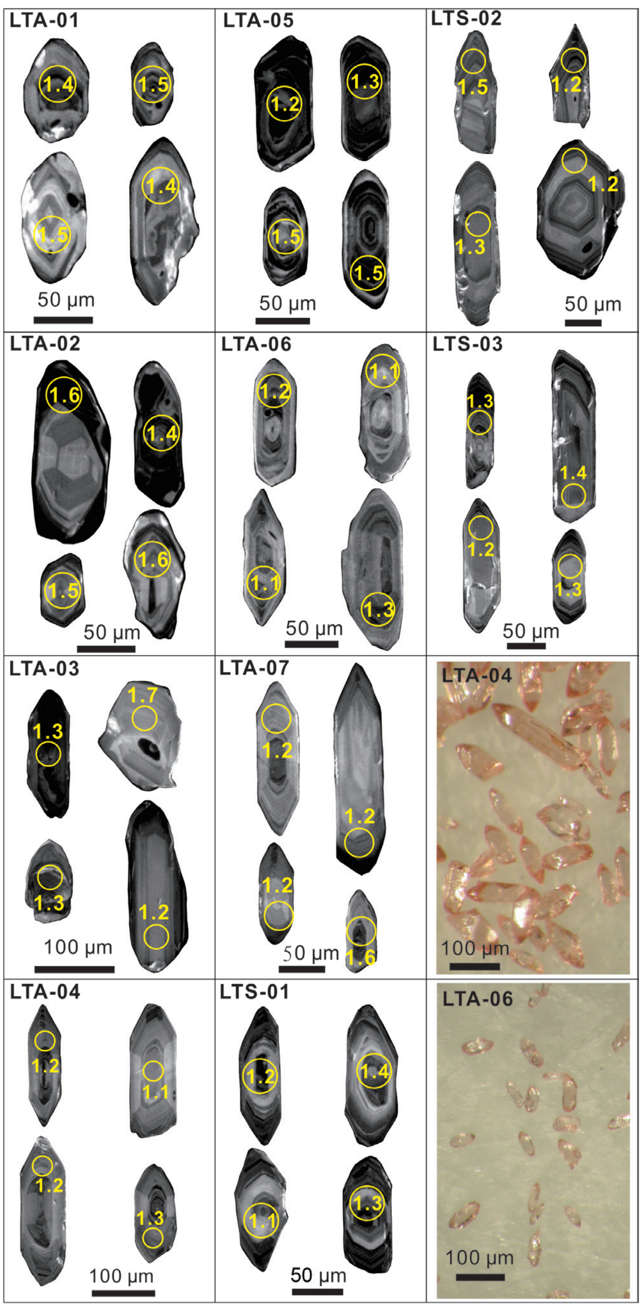

Fig. 4. Selective cathodoluminescence (CL) and stereoscopic images of zircons from Lutao. Yellow circles denote laser spots, i.e., ~30 μm in diameter, with U-Pb ages (Ma) shown.

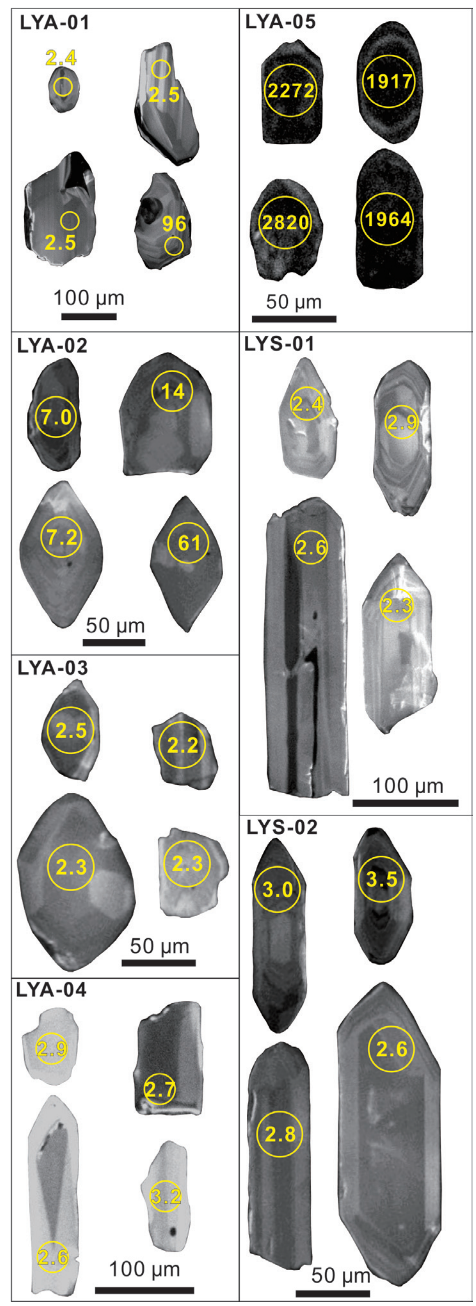

Fig. 5. Selective cathodoluminescence (CL) images of zircons from Lanyu. Yellow circles denote laser spots, i.e., ~30 μm in diameter, with U-Pb ages (Ma) shown.

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 Isoplot v. 3.0 (Ludwig 2003). Given that precise measurements of $^{207}Pb/^{235}U$ and $^{207}Pb/^{206}Pb$ ratios are feasible usually only for Precambrian zircons, due largely to the fact that ^{235}U now comprises less than 1% of natural U and thus relatively little ^{207}Pb can be produced in the Phanerozoic (cf. Ireland and Williams 2003); $^{206}Pb/^{238}U$ ages are taken to indicate the crystallization ages of young zircons in this study. Note that $^{207}Pb/^{206}Pb$ 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 $^{206}Pb/^{238}U$ 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 $^{206}Pb/^{238}U$ ages of 1.08 ± 0.02 and 1.17 ± 0.02 Ma reported also for the Chilungshan dacites using a secondary ion microprobe CAMECA 1280 (Gao et al. 2010) and a zircon $^{206}Pb/^{238}U$ 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. Zircon U-Pb isotopic data of Chilungshan samples.

			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**	**$^{206}Pb/^{238}U$**	**± 1 s**	**$^{207}Pb/^{206}Pb$**	**± 1 s**	**$^{207}Pb/^{235}U$**	**± 1 s**	**$^{208}Pb/^{232}Th$**	**± 1 s**
TDC-01	457	0.326	0.00109	0.00161	0.00018	0.00002	0.04357	0.06004	0.00010	0.00003	**1.2**	**0.1**	-93	1401	1.0	2.0	2.0	0.6
TDC-02	350	0.424	0.00354	0.00157	0.00020	0.00002	0.12918	0.04601	0.00003	0.00002	**1.3**	**0.1**	2087	767	4.0	2.0	0.6	0.4
TDC-03	472	0.297	0.00152	0.00122	0.00017	0.00001	0.06359	0.04770	0.00007	0.00002	**1.1**	**0.1**	728	1249	2.0	1.0	1.4	0.4
TDC-04	456	0.279	0.00232	0.00121	0.00019	0.00001	0.08811	0.04183	0.00011	0.00003	**1.2**	**0.1**	1385	1099	2.0	1.0	2.2	0.6
TDC-05	659	0.267	0.00183	0.00101	0.00018	0.00001	0.07220	0.03628	0.00002	0.00002	**1.2**	**0.1**	992	1126	2.0	1.0	0.4	0.4
TDC-06	363	0.319	0.00412	0.00147	0.00019	0.00002	0.15647	0.04163	0.00006	0.00003	**1.2**	**0.1**	2418	671	4.0	1.0	1.2	0.6
TDC-07	576	0.526	0.00130	0.00091	0.00016	0.00001	0.06024	0.03881	0.00004	0.00001	**1.0**	**0.1**	612	1193	1.3	0.9	0.8	0.2
TDC-08	612	0.353	0.00193	0.00092	0.00018	0.00001	0.07855	0.03357	0.00004	0.00002	**1.2**	**0.1**	1161	991	2.0	0.9	0.8	0.4
TDC-09	579	0.446	0.00171	0.00095	0.00019	0.00001	0.06358	0.03234	0.00006	0.00001	**1.2**	**0.1**	728	1037	1.7	1.0	1.2	0.2
TDC-11	564	0.424	0.00202	0.00070	0.00018	0.00001	0.08108	0.02458	0.00005	0.00001	**1.2**	**0.1**	1223	682	2.0	0.7	1.1	0.2

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

Table 2. (Continued)

Spot	U (ppm)	Th/U	U-Th-Pb ratios								Ages (Ma)							
			^{207}Pb/^{235}U	± 1 s	^{206}Pb/^{238}U	± 1 s	^{207}Pb/^{206}Pb	± 1 s	^{208}Pb/^{232}Th	± 1 s	^{206}Pb/^{238}U	± 1 s	^{207}Pb/^{206}Pb	± 1 s	^{207}Pb/^{235}U	± 1 s	^{208}Pb/^{232}Th	± 1 s
TDC-12	835	0.556	0.00044	0.00100	0.00014	0.00001	0.02273	0.05020	0.00006	0.00001	**0.9**	**0.1**	-623	1254	1.0	1.0	1.2	0.2
TDC-13	469	0.292	0.00033	0.00100	0.00015	0.00001	0.01654	0.04913	0.00007	0.00002	**1.0**	**0.1**	-946	1284	1.0	1.0	1.4	0.4
TDC-14	660	0.426	0.00184	0.00075	0.00017	0.00001	0.07915	0.02815	0.00007	0.00001	**1.1**	**0.1**	1176	888	1.9	0.8	1.4	0.2
TDC-15	599	0.549	0.00092	0.00086	0.00016	0.00001	0.04170	0.03665	0.00005	0.00001	**1.0**	**0.1**	-194	1020	0.9	0.9	1.0	0.2
TDC-16	438	0.298	0.00029	0.00104	0.00017	0.00001	0.01240	0.04381	0.00008	0.00002	**1.1**	**0.1**	-1183	1272	1.0	1.0	1.6	0.4
TDC-17	374	0.305	0.00347	0.00128	0.00017	0.00001	0.14748	0.04576	0.00005	0.00002	**1.1**	**0.1**	2317	653	4.0	1.0	1.0	0.1
TDC-19	1020	0.521	0.00129	0.00045	0.00017	0.00001	0.05639	0.01675	0.00008	0.00001	**1.1**	**0.1**	468	559	1.3	0.5	1.6	0.2
TDC-21	396	0.275	0.00100	0.00111	0.00015	0.00001	0.04836	0.05080	0.00005	0.00003	**1.0**	**0.1**	117	1331	1.0	1.0	1.0	0.6
TDC-22	797	0.667	0.00159	0.00055	0.00015	0.00001	0.07729	0.02221	0.00008	0.00001	**1.0**	**0.1**	1129	650	1.6	0.6	1.6	0.2

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

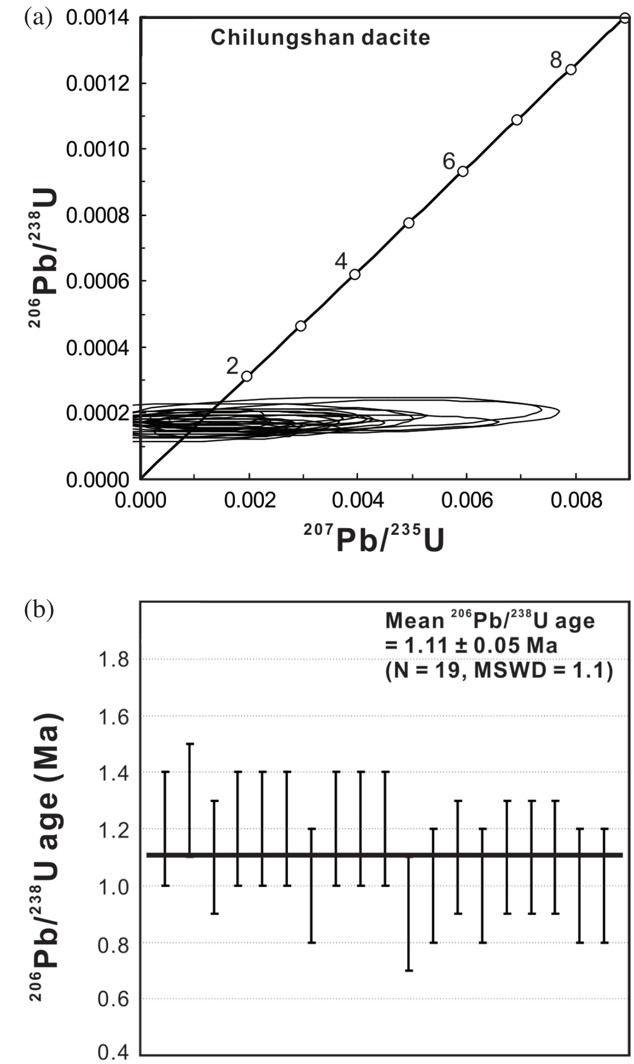

Fig. 6. (a) Concordia diagram and (b) weighted mean ^{206}Pb/^{238}U ages of magmatic zircons of a dacite sample from the Chilungshan volcano. The numeric (N) denotes the number of zircon.

dating results are summarized in Table 1, listed grain by grain in Table 3, and plotted in concordia and age distribution diagrams (Figs. 7 and 8). All the dated Lutao zircons have high U concentrations (175 - 4979 ppm) and high Th/U ratios (2.9 - 0.3), typical of igneous origin (cf. Rubatto 2002). Below we describe the results of the volcanic rocks and then sands, following the bottom to top sequences of the geological map (Fig. 1a). In addition, ages obtained by other methods in previous studies from each of the volcanic units will be outlined for comparison.

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, Fig. 8b), and LTA-03 that yielded a weighted mean ^{206}Pb/^{238}U

Table 3. Zircon U-Pb isotopic data of Lutao samples.

Spot	U (ppm)	Th/U	U-Th-Pb ratios								Ages (Ma)							
			$^{207}Pb/^{235}U$	± 1 s	$^{206}Pb/^{238}U$	± 1 s	$^{207}Pb/^{206}Pb$	± 1 s	$^{208}Pb/^{232}Th$	± 1 s	$^{206}Pb/^{238}U$	± 1 s	$^{207}Pb/^{206}Pb$	± 1 s	$^{207}Pb/^{235}U$	± 1 s	$^{208}Pb/^{232}Th$	± 1 s
LTA-01 (Huoshaoshan andesite)																		
LTA01-01	251	0.420	5.12369	0.11530	0.33062	0.00702	0.11241	0.00111	0.10601	0.00334	1841	34	***1839***	***17***	1840	19	2037	61
LTA01-02	1719	1.667	0.00233	0.00064	0.00022	0.00001	0.07794	0.01829	0.00009	0.00001	**1.4**	**0.1**	1145	482	2.4	0.6	1.8	0.2
LTA01-03	593	0.962	0.00197	0.00134	0.00018	0.00002	0.07928	0.04616	0.00007	0.00001	**1.2**	**0.1**	1179	1061	2.0	1.0	1.4	0.2
LTA01-04	468	1.333	0.00098	0.00166	0.00015	0.00002	0.04839	0.07621	0.00008	0.00001	**1.0**	**0.1**	118	1560	1.0	2.0	1.6	0.2
LTA01-05	896	0.709	0.00129	0.00068	0.00020	0.00002	0.04696	0.02229	0.00007	0.00003	**1.3**	**0.1**	47	794	1.3	0.7	1.4	0.5
LTA01-06	375	1.333	0.00108	0.00284	0.00017	0.00003	0.04674	0.11619	0.00006	0.00004	**1.1**	**0.2**	36	2950	1.0	3.0	1.2	0.8
LTA01-07	506	0.820	0.00199	0.00139	0.00014	0.00002	0.10218	0.05858	0.00008	0.00001	**0.9**	**0.1**	1664	1194	2.0	1.0	1.6	0.2
LTA01-08	406	1.205	0.00078	0.00096	0.00012	0.00001	0.04643	0.05361	0.00007	0.00003	**0.8**	**0.1**	20	1348	0.8	1.0	1.4	0.6
LTA01-09	868	0.840	0.00211	0.00100	0.00024	0.00002	0.06346	0.02542	0.00012	0.00001	**1.5**	**0.1**	724	779	2.0	1.0	2.4	0.2
LTA01-10	1305	1.724	0.00150	0.00123	0.00020	0.00002	0.05301	0.03887	0.00006	0.00001	**1.3**	**0.1**	329	1088	2.0	1.0	1.3	0.2
LTA01-11	1824	1.786	0.00108	0.00013	0.00017	0.00001	0.04640	0.00505	0.00008	0.00001	**1.1**	**0.1**	19	219	1.1	0.1	1.7	0.3
LTA01-12	429	0.971	0.00361	0.00242	0.00023	0.00003	0.11344	0.06306	0.00020	0.00003	**1.5**	**0.2**	1855	1207	4.0	2.0	4.0	0.6
LTA01-13	392	0.971	0.00125	0.00238	0.00027	0.00003	0.03317	0.05986	0.00010	0.00002	**1.7**	**0.2**	-149	1398	1.0	2.0	2.0	0.4
LTA01-14	513	0.885	0.00239	0.00165	0.00019	0.00002	0.09052	0.05408	0.00010	0.00002	**1.2**	**0.1**	1437	1222	2.0	2.0	2.0	0.4
LTA01-15	1779	1.667	0.00242	0.00059	0.00023	0.00001	0.07710	0.01585	0.00008	0.00001	**1.5**	**0.1**	1124	465	2.5	0.6	1.6	0.2
LTA01-16	400	0.781	1.08249	0.02499	0.12062	0.00254	0.06509	0.00066	0.04181	0.00130	***734***	***15***	777	21	745	12	828	25
LTA01-17	1216	1.515	0.00248	0.00118	0.00024	0.00002	0.07516	0.03054	0.00007	0.00001	**1.5**	**0.1**	1073	821	3.0	1.0	1.5	0.1
LTA01-18	491	1.639	0.00253	0.00416	0.00023	0.00005	0.07885	0.11433	0.00007	0.00002	**1.5**	**0.3**	1168	2096	3.0	4.0	1.4	0.5
LTA01-21	427	0.893	0.00056	0.00236	0.00020	0.00003	0.02067	0.08433	0.00007	0.00002	**1.3**	**0.2**	-726	2017	1.0	2.0	1.4	0.4
LTA01-22	4839	0.250	0.11957	0.00282	0.01702	0.00036	0.05097	0.00052	0.00584	0.00022	***109***	***2***	239	26	115	3	118	4
LTA01-24	317	1.587	0.00626	0.00217	0.00024	0.00003	0.18817	0.04524	0.00006	0.00001	**1.5**	**0.2**	2726	414	6.0	2.0	1.2	0.2
LTA01-25	458	1.075	0.00151	0.00115	0.00023	0.00002	0.04677	0.03217	0.00008	0.00004	**1.5**	**0.1**	38	994	2.0	1.0	1.7	0.7
LTA01-26	978	2.326	0.00119	0.00046	0.00019	0.00001	0.04652	0.01571	0.00007	0.00001	**1.2**	**0.1**	25	554	1.2	0.5	1.5	0.2
LTA01-27	539	0.685	0.00018	0.00161	0.00017	0.00002	0.00777	0.06868	0.00007	0.00002	**1.1**	**0.1**	-1471	2001	1.0	2.0	1.4	0.4
Mean $^{206}Pb/^{238}U$ age = 1.24 ± 0.08 Ma (N = 29, MSWD = 3.2)																		

Table 3. (Continued)

			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	$^{206}Pb/^{238}U$	± 1 s	$^{207}Pb/^{206}Pb$	± 1 s	$^{207}Pb/^{235}U$	± 1 s	$^{208}Pb/^{232}Th$	± 1 s
LTA-01 (Huoshaoshan andesite)																		
LTA01-28	895	1.639	0.00132	0.00107	0.00018	0.00002	0.05250	0.03739	0.00006	0.00001	**1.2**	**0.1**	307	1038	1.0	1.0	1.2	0.2
LTA01-29	768	1.818	0.00172	0.00085	0.00021	0.00001	0.05875	0.02654	0.00007	0.00001	**1.4**	**0.1**	558	766	1.7	0.9	1.4	0.2
LTA01-30	398	1.818	0.00096	0.00190	0.00015	0.00003	0.04651	0.08556	0.00006	0.00002	**1.0**	**0.2**	24	1672	1.0	2.0	1.3	0.4
LTA01-31	598	0.885	0.05132	0.00299	0.00808	0.00018	0.04607	0.00210	0.00269	0.00012	***52***	***1***	1	87	51	3	54	2
LTA01-32	2817	2.174	0.00250	0.00038	0.00020	0.00001	0.09263	0.01011	0.00007	0.00001	**1.3**	**0.1**	1480	218	2.5	0.4	1.4	0.2
LTA01-33	374	1.149	0.00246	0.00250	0.00017	0.00003	0.10634	0.09001	0.00005	0.00002	**1.1**	**0.2**	1738	1790	2.0	3.0	1.0	0.4
LTA01-34	324	1.149	0.00225	0.00209	0.00017	0.00002	0.09627	0.07938	0.00007	0.00002	**1.1**	**0.1**	1553	1555	2.0	2.0	1.4	0.4
LTA01-35	1946	1.818	0.00024	0.00036	0.00017	0.00001	0.00995	0.01440	0.00006	0.00001	**1.1**	**0.1**	-1332	756	0.2	0.4	1.2	0.2
LTA01-36	613	1.190	0.00197	0.00108	0.00018	0.00001	0.07769	0.03875	0.00006	0.00001	**1.2**	**0.1**	1139	1043	2.0	1.0	1.2	0.2
Mean $^{206}Pb/^{238}U$ age = 1.24 ± 0.08 Ma (N = 29, MSWD = 3.2)																		
LTA-02 (Ameishan volc. breccia)																		
LTA02-01	1737	0.847	0.00104	0.00039	0.00021	0.00001	0.03537	0.01177	0.00007	0.00001	**1.4**	**0.1**	-59	484	1.1	0.4	1.4	0.2
LTA02-04	1260	0.893	0.00023	0.00053	0.00023	0.00001	0.00747	0.01692	0.00007	0.00001	**1.5**	**0.1**	-1490	923	0.2	0.5	1.4	0.2
LTA02-05	1389	0.962	0.00076	0.00062	0.00025	0.00001	0.02243	0.01750	0.00008	0.00001	**1.6**	**0.1**	-637	746	0.8	0.6	1.6	0.2
LTA02-06	605	1.316	0.00151	0.00141	0.00024	0.00002	0.04651	0.04056	0.00009	0.00003	**1.5**	**0.1**	24	1135	2.0	1.0	1.7	0.6
LTA02-07	446	0.752	0.00098	0.00415	0.00023	0.00005	0.03110	0.12565	0.00018	0.00005	**1.5**	**0.3**	-236	2899	1.0	4.0	4.0	1.0
LTA02-08	806	1.471	0.00031	0.00094	0.00022	0.00001	0.01037	0.03102	0.00008	0.00001	**1.4**	**0.1**	-1306	1104	0.3	1.0	1.6	0.2
LTA02-09	2538	1.538	0.00202	0.00090	0.00024	0.00001	0.06162	0.02487	0.00007	0.00001	**1.5**	**0.1**	661	759	2.0	0.9	1.5	0.1
LTA02-10	217	0.498	0.00201	0.00280	0.00021	0.00003	0.06865	0.08778	0.00006	0.00006	**1.4**	**0.2**	888	1898	2.0	3.0	1.0	1.0
LTA02-11	2140	1.136	0.00173	0.00047	0.00022	0.00001	0.05667	0.01313	0.00009	0.00001	**1.4**	**0.1**	479	454	1.8	0.5	1.8	0.2
LTA02-12	758	1.639	0.00849	0.00430	0.00024	0.00005	0.25970	0.08344	0.00006	0.00003	**1.5**	**0.3**	3245	724	9.0	4.0	1.3	0.5
LTA02-13	753	0.781	0.00426	0.00150	0.00018	0.00002	0.16977	0.04358	0.00008	0.00002	**1.2**	**0.1**	2555	525	4.0	2.0	1.6	0.4
LTA02-14	956	1.389	0.00164	0.00009	0.00026	0.00001	0.04625	0.00137	0.00013	0.00001	**1.7**	**0.1**	11	63	1.7	0.1	2.5	0.3
LTA02-15	759	1.087	0.00029	0.00098	0.00024	0.00001	0.00880	0.02941	0.00010	0.00001	**1.5**	**0.1**	-1405	1122	0.3	1.0	2.0	0.2
Mean $^{206}Pb/^{238}U$ age = 1.44 ± 0.06 Ma (N = 20, MSWD = 1.5)																		

Table 3. (Continued)

			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**	**$^{206}Pb/^{238}U$**	**± 1 s**	**$^{207}Pb/^{206}Pb$**	**± 1 s**	**$^{207}Pb/^{235}U$**	**± 1 s**	**$^{208}Pb/^{232}Th$**	**± 1 s**
							LTA-02 (Ameishan volc. breccia)											
LTA02-16	817	1.613	0.00133	0.00065	0.00020	0.00001	0.04714	0.02159	0.00007	0.00001	**1.3**	**0.1**	56	781	1.3	0.7	1.4	0.2
LTA02-17	331	1.351	0.15759	0.00498	0.02089	0.00046	0.05473	0.00083	0.00707	0.00022	***133***	***3***	401	36	149	4	142	4
LTA02-18	1320	0.405	0.00043	0.00054	0.00023	0.00001	0.01358	0.01652	0.00012	0.00001	**1.5**	**0.1**	-1114	747	0.4	0.5	2.4	0.2
LTA02-19	1484	0.452	0.00072	0.00047	0.00022	0.00001	0.02335	0.01429	0.00008	0.00001	**1.4**	**0.1**	-592	640	0.7	0.5	1.6	0.2
LTA02-20	461	0.629	8.71367	0.24372	0.39489	0.00918	0.16004	0.00198	0.11380	0.00625	2145	42	***2456***	***19***	2309	25	2178	113
LTA02-21	587	1.042	0.00392	0.00120	0.00037	0.00002	0.07689	0.01988	0.00012	0.00001	***2.4***	***0.1***	1118	487	4.0	1.0	2.4	0.2
LTA0222C	569	1.124	0.00265	0.00123	0.00022	0.00002	0.08871	0.03410	0.00010	0.00001	**1.4**	**0.1**	1398	858	3.0	1.0	2.0	0.2
LTA0222R	1613	0.476	0.00177	0.00043	0.00025	0.00001	0.05233	0.01087	0.00008	0.00001	**1.6**	**0.1**	300	387	1.8	0.4	1.6	0.2
LTA02-23	153	0.629	6.85454	0.18462	0.37465	0.00790	0.13272	0.00161	0.11422	0.00636	2051	37	***2134***	***21***	2093	24	2186	115
LTA02-24	4426	0.667	0.00063	0.00017	0.00021	0.00001	0.02240	0.00511	0.00006	0.00001	**1.4**	**0.1**	-639	240	0.6	0.2	1.2	0.2
LTA02-25	1625	1.220	0.00120	0.00051	0.00019	0.00001	0.04665	0.01836	0.00007	0.00001	**1.2**	**0.1**	31	632	1.2	0.5	1.3	0.2
Mean $^{206}Pb/^{238}U$ age = 1.44 ± 0.06 Ma (N = 20, MSWD = 1.5)																		
							LTA-03 (Ameishan volc. breccia)											
LTA03-01	1587	0.288	5.06478	0.14943	0.28183	0.00606	0.13034	0.00170	0.08012	0.00168	1601	30	***2103***	***24***	1830	25	1558	31
LTA03-02	12516	1.515	0.00184	0.00027	0.00029	0.00001	0.04654	0.00578	0.00010	0.00001	**1.8**	**0.1**	26	239	1.9	0.3	2.1	0.2
LTA03-03	713	0.559	5.31954	0.11737	0.32919	0.00692	0.11722	0.00114	0.09802	0.00292	1834	34	***1914***	***17***	1872	19	1890	54
LTA03-04	446	0.787	0.00063	0.00155	0.00023	0.00002	0.02013	0.04796	0.00008	0.00002	**1.5**	**0.1**	-754	1232	1.0	2.0	1.6	0.4
LTA03-05	1184	1.587	0.00252	0.00077	0.00023	0.00001	0.08034	0.02146	0.00008	0.00001	**1.5**	**0.1**	1205	513	2.6	0.8	1.6	0.2
LTA03-06	810	1.563	0.00166	0.00039	0.00026	0.00001	0.04653	0.01021	0.00009	0.00001	**1.7**	**0.1**	25	357	1.7	0.4	1.9	0.2
LTA03-07	791	0.893	0.00780	0.00374	0.00023	0.00004	0.24206	0.08013	0.00006	0.00005	**1.5**	**0.3**	3134	757	8.0	4.0	1.3	0.9
LTA03-08	832	0.855	6.13619	0.14209	0.35967	0.00775	0.12375	0.00125	0.11065	0.00391	1981	37	***2011***	***18***	1995	20	2121	71
LTA03-09	1302	0.862	0.00181	0.00010	0.00028	0.00002	0.04622	0.00077	0.00020	0.00002	**1.8**	**0.1**	9	31	1.8	0.1	4.0	0.5
LTA03-10	538	0.289	5.31718	0.11843	0.33772	0.00706	0.11421	0.00111	0.10462	0.00349	1876	34	***1867***	***19***	1872	19	2011	64
LTA03-11	619	1.075	0.00218	0.00139	0.00034	0.00002	0.04585	0.02683	0.00037	0.00002	***2.2***	***0.1***	-10	929	2.0	1.0	7.5	0.4
Mean $^{206}Pb/^{238}U$ age = 1.54 ± 0.12 Ma (N = 12, MSWD = 2.7)																		

Table 3. (Continued)

			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	$^{206}Pb/^{238}U$	± 1 s	$^{207}Pb/^{206}Pb$	± 1 s	$^{207}Pb/^{235}U$	± 1 s	$^{208}Pb/^{232}Th$	± 1 s
LTA-03 (Ameishan volc. breccia)																		
LTA03-12	1132	0.276	5.46454	0.14280	0.33949	0.00772	0.11679	0.00133	0.11627	0.00565	1884	37	***1908***	***20***	1895	22	2223	102
LTA03-13	154	0.980	0.09033	0.00594	0.01500	0.00036	0.04368	0.00198	0.00512	0.00021	***96***	***2***	-87	94	88	6	103	4
LTA03-14	949	0.625	0.00249	0.00150	0.00022	0.00002	0.08281	0.04225	0.00006	0.00001	**1.4**	**0.1**	1265	1182	3.0	2.0	1.3	0.3
LTA03-15	1270	1.235	0.00110	0.00056	0.00023	0.00001	0.03417	0.01607	0.00009	0.00001	**1.5**	**0.1**	-107	611	1.1	0.6	1.8	0.2
LTA03-16	1897	0.917	0.00083	0.00044	0.00020	0.00001	0.02978	0.01446	0.00007	0.00001	**1.3**	**0.1**	-294	646	0.8	0.4	1.4	0.2
LTA03-17	455	1.613	0.00127	0.00187	0.00019	0.00003	0.04909	0.06588	0.00006	0.00002	**1.2**	**0.2**	152	1522	1.0	2.0	1.2	0.3
LTA03-18	345	0.763	0.00116	0.00229	0.00026	0.00003	0.03190	0.05968	0.00011	0.00002	**1.7**	**0.2**	-202	1384	1.0	2.0	2.2	0.4
LTA03-19	1081	1.408	0.00033	0.00065	0.00022	0.00001	0.01095	0.02112	0.00009	0.00001	**1.4**	**0.1**	-1271	882	0.3	0.7	1.8	0.2
Mean $^{206}Pb/^{238}U$ age = 1.54 ± 0.12 Ma (N = 12, MSWD = 2.7)																		
LTA-04 (Kungkuan andesite)																		
LTA04-01	732	0.654	0.00079	0.00088	0.00019	0.00001	0.03105	0.03312	0.00007	0.00001	**1.2**	**0.1**	-238	986	0.8	0.9	1.4	0.2
LTA04-02	743	0.662	0.00128	0.00030	0.00020	0.00001	0.04638	0.01015	0.00010	0.00003	**1.3**	**0.1**	17	334	1.3	0.3	2.0	0.5
LTA04-03	904	1.064	0.00257	0.00090	0.00019	0.00001	0.09614	0.02920	0.00006	0.00001	**1.2**	**0.1**	1551	661	2.6	0.9	1.2	0.2
LTA04-04	823	1.176	0.00210	0.00097	0.00019	0.00001	0.07813	0.03244	0.00008	0.00001	**1.2**	**0.1**	1150	798	2.1	1.0	1.6	0.2
LTA04-05	926	0.658	0.00223	0.00075	0.00020	0.00001	0.08277	0.02418	0.00008	0.00001	**1.3**	**0.1**	1264	591	2.3	0.8	1.6	0.2
LTA04-06	405	0.559	0.00135	0.00154	0.00017	0.00002	0.05707	0.05913	0.00007	0.00002	**1.1**	**0.1**	494	1347	1.0	2.0	1.4	0.4
LTA04-07	4348	0.427	0.00134	0.00016	0.00021	0.00001	0.04537	0.00360	0.00007	0.00001	**1.4**	**0.1**	-1	163	1.4	0.2	1.4	0.2
LTA04-08	213	0.518	0.00418	0.00302	0.00015	0.00003	0.20830	0.11445	0.00004	0.00005	**1.0**	**0.2**	2892	1372	4.0	3.0	1.0	1.0
LTA04-09	794	1.190	0.00115	0.00081	0.00020	0.00001	0.04122	0.02719	0.00010	0.00001	**1.3**	**0.1**	-220	833	1.2	0.8	2.0	0.2
LTA04-10	730	0.641	0.00049	0.00081	0.00021	0.00001	0.01718	0.02767	0.00006	0.00001	**1.4**	**0.1**	-911	991	0.5	0.8	1.2	0.2
LTA04-11	1574	1.613	0.00097	0.00040	0.00018	0.00001	0.03806	0.01382	0.00007	0.00001	**1.2**	**0.1**	-406	590	1.0	0.4	1.4	0.2
LTA04-12	666	0.641	0.00117	0.00075	0.00018	0.00002	0.04672	0.02737	0.00007	0.00003	**1.2**	**0.1**	35	932	1.2	0.8	1.4	0.5
LTA04-13	765	0.709	0.00051	0.00151	0.00021	0.00002	0.01773	0.05098	0.00008	0.00002	**1.4**	**0.1**	-881	1268	1.0	2.0	1.6	0.4
LTA04-14	859	1.020	0.00076	0.00074	0.00019	0.00001	0.02899	0.02686	0.00005	0.00001	**1.2**	**0.1**	-329	931	0.8	0.8	1.0	0.2
Mean $^{206}Pb/^{238}U$ age = 1.25 ± 0.05 Ma (N = 30, MSWD = 1.5)																		

Table 3. (Continued)

			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**	**$^{206}Pb/^{238}U$**	**± 1 s**	**$^{207}Pb/^{206}Pb$**	**± 1 s**	**$^{207}Pb/^{235}U$**	**± 1 s**	**$^{208}Pb/^{232}Th$**	**± 1 s**
LTA-04 (Kungkuan andesite)																		
LTA04-15	1105	0.935	0.00064	0.00056	0.00019	0.00001	0.02381	0.01971	0.00006	0.00001	**1.2**	**0.1**	-570	810	0.6	0.6	1.2	0.2
LTA04-16	1112	0.909	0.00034	0.00062	0.00018	0.00001	0.01400	0.02483	0.00006	0.00001	**1.2**	**0.1**	-1090	974	0.3	0.6	1.2	0.2
LTA04-17	730	0.565	0.00056	0.00151	0.00020	0.00002	0.02033	0.05300	0.00008	0.00002	**1.3**	**0.1**	-744	1351	1.0	2.0	1.6	0.4
LTA04-18	1183	0.901	0.00074	0.00055	0.00018	0.00001	0.02926	0.02030	0.00005	0.00001	**1.2**	**0.1**	-317	861	0.8	0.6	1.0	0.2
LTA04-19	797	0.719	0.00101	0.00078	0.00019	0.00001	0.03781	0.02742	0.00005	0.00001	**1.2**	**0.1**	-421	1013	1.0	0.8	1.0	0.2
LTA04-20	633	0.568	0.00123	0.00158	0.00022	0.00002	0.03991	0.04803	0.00017	0.00002	**1.4**	**0.1**	-295	1334	1.0	2.0	3.4	0.4
LTA04-21	751	0.667	0.00180	0.00081	0.00019	0.00001	0.06929	0.02794	0.00004	0.00001	**1.2**	**0.1**	907	746	1.8	0.8	0.8	0.2
LTA04-22	870	0.794	0.00020	0.00080	0.00018	0.00001	0.00799	0.03156	0.00005	0.00001	**1.2**	**0.1**	-1457	1211	0.2	0.8	1.0	0.2
LTA04-23	446	1.111	0.00371	0.00145	0.00026	0.00002	0.10363	0.03351	0.00013	0.00001	**1.7**	**0.1**	1690	687	4.0	1.0	2.6	0.2
LTA04-24	838	0.578	0.00012	0.00094	0.00018	0.00001	0.00501	0.03899	0.00007	0.00001	**1.2**	**0.1**	-1655	1321	0.1	1.0	1.4	0.2
LTA04-25	2393	2.000	0.00101	0.00027	0.00017	0.00001	0.04190	0.00905	0.00006	0.00001	**1.1**	**0.1**	-183	325	1.0	0.3	1.2	0.2
LTA04-26	818	0.704	0.00010	0.00082	0.00018	0.00001	0.00412	0.03358	0.00004	0.00001	**1.2**	**0.1**	-1716	1282	0.1	0.8	0.8	0.2
LTA04-27	1103	1.000	0.00010	0.00067	0.00017	0.00001	0.00421	0.02798	0.00006	0.00001	**1.1**	**0.1**	-1710	1233	0.1	0.7	1.2	0.2
LTA04-28	636	0.529	0.00077	0.00100	0.00018	0.00001	0.03120	0.03897	0.00006	0.00001	**1.2**	**0.1**	-232	1040	1.0	1.0	1.2	0.2
LTA04-29	420	0.847	0.00249	0.00151	0.00018	0.00002	0.09982	0.05078	0.00005	0.00001	**1.2**	**0.1**	1621	1051	3.0	2.0	1.0	0.2
LTA04-30	616	0.621	0.00052	0.00100	0.00019	0.00001	0.01998	0.03748	0.00007	0.00001	**1.2**	**0.1**	-762	1063	1.0	1.0	1.4	0.2
Mean $^{206}Pb/^{238}U$ age = 1.25 ± 0.05 Ma (N = 30, MSWD = 1.5)																		
LTA-05 (Kungkuan andesite)																		
LTA05-01	559	0.763	0.00212	0.00115	0.00025	0.00002	0.06254	0.02950	0.00010	0.00001	**1.6**	**0.1**	693	844	2.0	1.0	2.0	0.2
LTA05-02	2166	2.564	0.00127	0.00032	0.00020	0.00001	0.04545	0.00946	0.00007	0.00001	**1.3**	**0.1**	-31	331	1.3	0.3	1.4	0.2
LTA05-03	2156	0.758	0.00099	0.00027	0.00019	0.00001	0.03861	0.00875	0.00006	0.00001	**1.2**	**0.1**	-372	330	1.0	0.3	1.2	0.2
LTA05-04	1341	0.617	0.00255	0.00061	0.00023	0.00001	0.08154	0.01639	0.00011	0.00001	**1.5**	**0.1**	1234	421	2.6	0.6	2.2	0.2
LTA05-05	537	1.724	0.00175	0.00138	0.00021	0.00002	0.05988	0.04338	0.00007	0.00001	**1.4**	**0.1**	599	1162	2.0	1.0	1.3	0.2
LTA05-06	727	1.389	0.00095	0.00010	0.00015	0.00001	0.04636	0.00451	0.00009	0.00001	**1.0**	**0.1**	16	211	1.0	0.1	1.8	0.3
Mean $^{206}Pb/^{238}U$ age = 1.36 ± 0.05 Ma (N = 38, MSWD = 1.7)																		

Table 3. (Continued)

Spot	U (ppm)	Th/U	U-Th-Pb ratios $^{207}Pb/^{235}U$	± 1 s	$^{206}Pb/^{238}U$	± 1 s	$^{207}Pb/^{206}Pb$	± 1 s	$^{208}Pb/^{232}Th$	± 1 s	Ages (Ma) $^{206}Pb/^{238}U$	± 1 s	$^{207}Pb/^{206}Pb$	± 1 s	$^{207}Pb/^{235}U$	± 1 s	$^{208}Pb/^{232}Th$	± 1 s
LTA-05 (Kungkuan andesite)																		
LTA05-07	489	1.020	0.00122	0.00100	0.00020	0.00001	0.04475	0.03468	0.00012	0.00001	**1.3**	**0.1**	-32	1065	1.0	1.0	2.4	0.2
LTA05-08	175	1.042	0.00272	0.00471	0.00031	0.00006	0.06400	0.09982	0.00017	0.00004	**2.0**	**0.4**	742	2054	3.0	5.0	3.4	0.8
LTA05-09	1250	1.266	0.00131	0.00019	0.00021	0.00001	0.04636	0.00586	0.00008	0.00001	**1.3**	**0.1**	16	250	1.3	0.2	1.7	0.2
LTA05-10	1883	0.787	0.00118	0.00031	0.00020	0.00001	0.04228	0.00925	0.00008	0.00001	**1.3**	**0.1**	-162	314	1.2	0.3	1.6	0.2
LTA05-11	329	1.266	0.00258	0.00183	0.00022	0.00002	0.08544	0.05372	0.00010	0.00001	**1.4**	**0.1**	1326	1365	3.0	2.0	2.0	0.2
LTA05-12	4076	2.439	0.00125	0.00021	0.00019	0.00001	0.04648	0.00688	0.00008	0.00001	**1.3**	**0.1**	23	256	1.3	0.2	1.6	0.2
LTA05-13	543	0.595	0.00237	0.00117	0.00021	0.00002	0.08350	0.03431	0.00006	0.00001	**1.3**	**0.1**	1281	915	2.0	1.0	1.2	0.3
LTA05-14	348	1.053	0.00036	0.00200	0.00021	0.00003	0.01214	0.06589	0.00004	0.00002	**1.4**	**0.2**	-1199	1654	1.0	2.0	0.8	0.4
LTA05-15	1831	1.429	0.00128	0.00035	0.00020	0.00001	0.04663	0.01145	0.00007	0.00001	**1.3**	**0.1**	30	423	1.3	0.4	1.4	0.1
LTA05-16	496	1.053	0.00099	0.00113	0.00019	0.00002	0.03859	0.04043	0.00010	0.00001	**1.2**	**0.1**	-373	1139	1.0	1.0	2.0	0.2
LTA05-17	428	1.316	0.00096	0.00103	0.00020	0.00001	0.03527	0.03626	0.00006	0.00001	**1.3**	**0.1**	-63	1112	1.0	1.0	1.2	0.2
LTA05-18	1124	0.787	0.00132	0.00042	0.00020	0.00001	0.04737	0.01352	0.00007	0.00001	**1.3**	**0.1**	68	470	1.3	0.4	1.4	0.1
LTA05-19	1286	1.031	0.00071	0.00056	0.00019	0.00001	0.02787	0.02067	0.00008	0.00001	**1.2**	**0.1**	-379	881	0.7	0.6	1.6	0.2
LTA05-20	1160	1.176	0.00169	0.00041	0.00022	0.00001	0.05647	0.01144	0.00009	0.00001	**1.4**	**0.1**	471	414	1.7	0.4	1.8	0.2
LTA05-21	460	0.787	0.00156	0.00032	0.00024	0.00001	0.04632	0.00824	0.00013	0.00004	**1.6**	**0.1**	14	277	1.6	0.3	2.5	0.7
LTA05-22	1445	1.205	0.00128	0.00034	0.00020	0.00001	0.04668	0.01104	0.00007	0.00001	**1.3**	**0.1**	33	400	1.3	0.3	1.4	0.2
LTA05-23	606	1.667	0.00070	0.00129	0.00021	0.00002	0.02384	0.04190	0.00009	0.00001	**1.4**	**0.1**	-568	1057	1.0	1.0	1.8	0.2
LTA05-24	647	0.004	0.35987	0.00942	0.04255	0.00091	0.06133	0.00063	0.01311	0.00031	***269***	***6***	651	21	312	7	263	6
LTA05-25	908	0.637	0.07379	0.00409	0.01161	0.00029	0.04609	0.00167	0.00373	0.00010	***74***	***2***	3	74	72	4	75	2
LTA05-26	1119	1.205	0.00144	0.00038	0.00022	0.00001	0.04671	0.01117	0.00008	0.00001	**1.4**	**0.1**	34	360	1.5	0.4	1.6	0.2
LTA05-27	352	1.429	0.00137	0.00130	0.00024	0.00002	0.04101	0.03587	0.00009	0.00001	**1.5**	**0.1**	-232	1026	1.0	1.0	1.8	0.2
LTA05-28	540	1.515	0.00050	0.00095	0.00022	0.00002	0.01688	0.03070	0.00009	0.00001	**1.4**	**0.1**	-927	1035	0.5	1.0	1.8	0.2
LTA05-29	970	1.136	0.00180	0.00075	0.00021	0.00001	0.06113	0.02289	0.00007	0.00001	**1.4**	**0.1**	644	756	1.8	0.8	1.4	0.2
LTA05-30	726	1.149	0.00267	0.00089	0.00021	0.00001	0.09242	0.02691	0.00011	0.00001	**1.4**	**0.1**	1476	638	2.7	0.9	2.2	0.2

Mean $^{206}Pb/^{238}U$ age = 1.36 ± 0.05 Ma (N = 38, MSWD = 1.7)

Table 3. (Continued)

			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**	**$^{206}Pb/^{238}U$**	**± 1 s**	**$^{207}Pb/^{206}Pb$**	**± 1 s**	**$^{207}Pb/^{235}U$**	**± 1 s**	**$^{208}Pb/^{232}Th$**	**± 1 s**
LTA-05 (Kungkuan andesite)																		
LTA05-31	800	0.075	4.66439	0.12448	0.29575	0.00731	0.11439	0.00119	0.08518	0.00217	1670	36	***1870***	***19***	1761	22	1652	40
LTA05-33	1219	0.730	0.00356	0.00079	0.00040	0.00002	0.06490	0.01163	0.00012	0.00001	***2.6***	***0.1***	771	376	3.6	0.8	2.5	0.1
LTA05-34	1642	0.787	0.00276	0.00033	0.00023	0.00001	0.08598	0.00711	0.00008	0.00001	**1.5**	**0.1**	1338	145	2.8	0.3	1.6	0.2
LTA05-35	556	0.521	0.00195	0.00084	0.00025	0.00001	0.05557	0.02196	0.00011	0.00001	**1.6**	**0.1**	435	684	2.0	0.9	2.2	0.2
LTA05-36	1657	1.099	0.00228	0.00065	0.00023	0.00001	0.07056	0.01730	0.00007	0.00001	**1.5**	**0.1**	945	577	2.3	0.7	1.4	0.1
LTA05-37	1178	1.136	0.00440	0.00215	0.00024	0.00004	0.13266	0.04675	0.00007	0.00001	**1.5**	**0.2**	2134	756	4.0	2.0	1.4	0.2
LTA05-38	713	1.205	0.00023	0.00060	0.00020	0.00001	0.00820	0.02102	0.00006	0.00001	**1.3**	**0.1**	-1443	932	0.2	0.6	1.2	0.2
LTA05-39	234	0.613	0.00095	0.00190	0.00019	0.00002	0.03696	0.07044	0.00002	0.00003	**1.2**	**0.1**	-474	1655	1.0	2.0	0.4	0.6
LTA05-40	1767	1.449	0.00137	0.00024	0.00021	0.00001	0.04642	0.00704	0.00008	0.00001	**1.4**	**0.1**	20	300	1.4	0.2	1.6	0.2
LTA05-41	1412	2.083	0.00014	0.00031	0.00019	0.00001	0.00525	0.01138	0.00007	0.00001	**1.2**	**0.1**	-1638	793	0.1	0.3	1.4	0.2
LTA05-42	232	0.508	0.00168	0.00051	0.00026	0.00002	0.04613	0.01157	0.00028	0.00011	**1.7**	**0.2**	4	389	1.7	0.5	6.0	2.0
LTA05-43	935	0.917	0.00054	0.00048	0.00024	0.00001	0.01605	0.01367	0.00008	0.00001	**1.5**	**0.1**	-973	740	0.5	0.5	1.6	0.2
Mean $^{206}Pb/^{238}U$ age = 1.36 ± 0.05 Ma (N = 38, MSWD = 1.7)																		
LTA-06 (Kungkuan andesite)																		
LTA06-01	1048	0.833	0.00107	0.00048	0.00017	0.00001	0.04654	0.01845	0.00007	0.00001	**1.1**	**0.1**	26	673	1.1	0.5	1.4	0.2
LTA06-02	1040	0.813	0.00128	0.00016	0.00020	0.00001	0.04625	0.00470	0.00013	0.00003	**1.3**	**0.1**	11	232	1.3	0.2	2.5	0.6
LTA06-03	1469	1.429	0.00121	0.00024	0.00019	0.00001	0.04678	0.00838	0.00007	0.00001	**1.2**	**0.1**	38	317	1.2	0.2	1.4	0.2
LTA06-04	422	0.364	0.00448	0.00157	0.00021	0.00002	0.15217	0.04078	0.00011	0.00003	**1.4**	**0.1**	2370	529	5.0	2.0	2.2	0.6
LTA06-05	825	1.852	0.00203	0.00157	0.00018	0.00002	0.08339	0.05495	0.00005	0.00001	**1.1**	**0.1**	1278	1300	2.0	2.0	1.1	0.2
LTA06-06	1835	1.818	0.00108	0.00027	0.00019	0.00001	0.04051	0.00826	0.00007	0.00001	**1.2**	**0.1**	-260	304	1.1	0.3	1.4	0.2
LTA06-07	1000	0.746	0.00116	0.00055	0.00019	0.00001	0.04524	0.01933	0.00008	0.00001	**1.2**	**0.1**	-7	605	1.2	0.6	1.6	0.2
LTA06-08	1370	0.917	0.00132	0.00024	0.00020	0.00001	0.04663	0.00738	0.00008	0.00001	**1.3**	**0.1**	30	261	1.3	0.2	1.5	0.2
LTA06-09	589	0.746	0.00210	0.00085	0.00022	0.00001	0.06861	0.02541	0.00007	0.00001	**1.4**	**0.1**	887	721	2.1	0.9	1.4	0.1
LTA06-10	1153	0.962	0.00090	0.00048	0.00019	0.00001	0.03364	0.01637	0.00006	0.00001	**1.2**	**0.1**	-129	674	0.9	0.5	1.2	0.2
Mean $^{206}Pb/^{238}U$ age = 1.24 ± 0.04 Ma (N = 27, MSWD = 1.2)																		

Table 3. (Continued)

			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**	**$^{206}Pb/^{238}U$**	**± 1 s**	**$^{207}Pb/^{206}Pb$**	**± 1 s**	**$^{207}Pb/^{235}U$**	**± 1 s**	**$^{208}Pb/^{232}Th$**	**± 1 s**
LTA-06 (Kungkuan andesite)																		
LTA06-11	891	0.763	0.00262	0.00155	0.00019	0.00002	0.10055	0.05041	0.00006	0.00001	**1.2**	**0.1**	1634	1095	3.0	2.0	1.1	0.3
LTA06-12	861	1.282	0.00132	0.00035	0.00021	0.00001	0.04633	0.01057	0.00009	0.00002	**1.3**	**0.1**	15	379	1.3	0.4	1.8	0.3
LTA06-13	2278	0.575	0.00061	0.00024	0.00022	0.00001	0.02031	0.00717	0.00006	0.00001	**1.4**	**0.1**	-745	365	0.6	0.2	1.2	0.2
LTA06-14	878	0.758	0.00164	0.00059	0.00017	0.00001	0.06895	0.02123	0.00008	0.00001	**1.1**	**0.1**	897	643	1.7	0.6	1.6	0.2
LTA06-15	1010	1.000	0.00113	0.00069	0.00016	0.00001	0.05021	0.02831	0.00005	0.00001	**1.1**	**0.1**	205	907	1.1	0.7	1.0	0.2
LTA06-16	477	1.042	0.00015	0.00157	0.00022	0.00002	0.00517	0.05369	0.00008	0.00001	**1.4**	**0.1**	-1644	1533	1.0	2.0	1.6	0.2
LTA06-17	848	0.730	0.00136	0.00066	0.00016	0.00001	0.06193	0.02651	0.00005	0.00001	**1.0**	**0.1**	672	893	1.4	0.7	1.0	0.2
LTA06-18	487	1.250	0.00208	0.00109	0.00022	0.00002	0.06828	0.03032	0.00011	0.00001	**1.4**	**0.1**	877	934	2.0	1.0	2.2	0.2
LTA06-19	1196	1.299	0.00127	0.00038	0.00020	0.00001	0.04663	0.01308	0.00007	0.00001	**1.3**	**0.1**	31	402	1.3	0.4	1.4	0.2
LTA06-20	421	1.031	0.00083	0.00113	0.00019	0.00001	0.03252	0.04274	0.00008	0.00001	**1.2**	**0.1**	-176	1110	1.0	1.0	1.6	0.2
LTA06-21	478	0.909	0.00189	0.00093	0.00019	0.00001	0.07415	0.03302	0.00004	0.00001	**1.2**	**0.1**	1046	966	1.9	0.9	0.8	0.2
LTA06-22	885	0.833	0.00237	0.00084	0.00022	0.00001	0.07956	0.02499	0.00012	0.00001	**1.4**	**0.1**	1186	679	2.4	0.9	2.4	0.2
LTA06-23	987	1.020	0.00086	0.00044	0.00019	0.00001	0.03275	0.01522	0.00007	0.00001	**1.2**	**0.1**	-166	568	0.9	0.4	1.4	0.2
LTA06-24	1654	1.266	0.00119	0.00037	0.00018	0.00001	0.04665	0.01279	0.00007	0.00001	**1.2**	**0.1**	31	451	1.2	0.4	1.3	0.2
LTA06-25	942	0.787	0.00128	0.00060	0.00018	0.00001	0.05064	0.02150	0.00006	0.00001	**1.2**	**0.1**	225	748	1.3	0.6	1.2	0.2
LTA06-26	1392	1.163	0.00157	0.00077	0.00018	0.00001	0.06351	0.02825	0.00006	0.00001	**1.2**	**0.1**	725	837	1.6	0.8	1.1	0.2
LTA06-27	847	0.714	0.00010	0.00071	0.00018	0.00001	0.00395	0.02785	0.00007	0.00001	**1.2**	**0.1**	-1728	1198	0.1	0.7	1.4	0.2
Mean $^{206}Pb/^{238}U$ age = 1.24 ± 0.04 Ma (N = 27, MSWD = 1.2)																		
LTA-07 (Niutzushan volc. breccia)																		
LTA07-01	536	1.087	0.00131	0.00051	0.00020	0.00001	0.04671	0.01728	0.00007	0.00002	**1.3**	**0.1**	35	576	1.3	0.5	1.4	0.3
LTA07-02	577	1.695	0.00331	0.00087	0.00019	0.00001	0.12457	0.02699	0.00007	0.00001	**1.2**	**0.1**	2023	436	3.4	0.9	1.4	0.2
LTA07-03	179	0.355	7.70487	0.17343	0.40323	0.00842	0.13859	0.00136	0.13456	0.00440	2184	39	***2210***	***16***	2197	20	2552	78
LTA07-04	671	0.794	9.57120	0.24836	0.44431	0.01075	0.15626	0.00177	0.13838	0.00526	2370	48	***2416***	***21***	2394	24	2620	93
LTA07-05	712	1.075	0.00161	0.00079	0.00024	0.00002	0.04787	0.02061	0.00008	0.00001	**1.6**	**0.1**	93	720	1.6	0.8	1.6	0.2
Mean $^{206}Pb/^{238}U$ age = 1.28 ± 0.06 Ma (N = 34, MSWD = 2.4)																		

Table 3. (Continued)

			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**	**$^{206}Pb/^{238}U$**	**± 1 s**	**$^{207}Pb/^{206}Pb$**	**± 1 s**	**$^{207}Pb/^{235}U$**	**± 1 s**	**$^{208}Pb/^{232}Th$**	**± 1 s**
LTA-07 (Niutzushan volc. breccia)																		
LTA07-06	1078	1.111	0.00061	0.00043	0.00019	0.00001	0.02376	0.01563	0.00006	0.00001	**1.2**	**0.1**	-572	669	0.6	0.4	1.2	0.2
LTA07-07	520	1.136	0.00188	0.00098	0.00022	0.00001	0.06262	0.03010	0.00007	0.00001	**1.4**	**0.1**	695	1070	1.9	1.0	1.3	0.1
LTA07-08	966	2.703	0.00088	0.00053	0.00018	0.00001	0.03506	0.01938	0.00006	0.00001	**1.2**	**0.1**	-71	870	0.9	0.5	1.2	0.2
LTA07-09	526	1.163	0.00112	0.00033	0.00018	0.00001	0.04633	0.01165	0.00008	0.00002	**1.1**	**0.1**	15	408	1.1	0.3	1.6	0.4
LTA07-10	769	0.139	8.73984	0.20144	0.42862	0.00952	0.14789	0.00150	0.13205	0.00383	2299	43	***2322***	***17***	2311	21	2507	68
LTA07-11	338	0.885	0.00196	0.00145	0.00019	0.00002	0.07683	0.04969	0.00006	0.00001	**1.2**	**0.1**	1117	1237	2.0	1.0	1.2	0.2
LTA07-12	1165	0.295	0.00237	0.00061	0.00019	0.00001	0.08879	0.01918	0.00006	.	**1.2**	**0.1**	1400	443	2.4	0.6	1.2	.
LTA07-13	724	0.532	0.00142	0.00063	0.00020	0.00001	0.05099	0.02036	0.00007	0.00001	**1.3**	**0.1**	240	651	1.4	0.6	1.4	0.2
LTA07-14	1057	1.471	0.00036	0.00043	0.00019	0.00001	0.01368	0.01570	0.00006	0.00001	**1.2**	**0.1**	-1108	807	0.4	0.4	1.2	0.2
LTA07-15	902	0.500	0.00082	0.00051	0.00018	0.00001	0.03269	0.01871	0.00004	0.00001	**1.2**	**0.1**	-169	671	0.8	0.5	0.8	0.2
LTA07-16	360	0.752	0.00105	0.00138	0.00021	0.00002	0.03671	0.04513	0.00006	0.00002	**1.4**	**0.1**	-5	1225	1.0	1.0	1.2	0.4
LTA07-17	595	1.786	0.00012	0.00098	0.00017	0.00001	0.00523	0.04243	0.00005	0.00001	**1.1**	**0.1**	-1640	1344	0.1	1.0	1.0	0.2
LTA07-18	402	1.266	0.00710	0.00214	0.00021	0.00003	0.24778	0.04552	0.00007	0.00001	**1.4**	**0.2**	3171	268	7	2	1.4	0.2
LTA07-19	801	1.124	0.00014	0.00063	0.00016	0.00001	0.00607	0.02697	0.00005	0.00001	**1.0**	**0.1**	-1583	1100	0.1	0.6	1	0.2
LTA07-20	912	2.500	0.00021	0.00078	0.00021	0.00001	0.00717	0.02632	0.00006	0.00001	**1.4**	**0.1**	-1510	1050	0.2	0.8	1.2	0.2
LTA07-21	804	1.235	0.00106	0.00026	0.00016	0.00001	0.04670	0.01060	0.00007	0.00001	**1.1**	**0.1**	34	359	1.1	0.3	1.4	0.2
LTA07-22	430	0.285	10.69786	0.25608	0.47113	0.01080	0.16470	0.00173	0.14204	0.00436	2489	47	***2504***	***16***	2497	22	2685	77
LTA07-23	93	0.685	9.26454	0.25554	0.44370	0.01111	0.15145	0.00182	0.13333	0.00537	2367	50	***2362***	***20***	2365	25	2530	96
LTA07-24	1521	0.315	0.00537	0.00138	0.00024	0.00002	0.16099	0.02982	0.00007	0.00001	**1.6**	**0.1**	2466	301	5.0	1.0	1.4	0.3
LTA07-25	962	1.299	0.00134	0.00023	0.00021	0.00001	0.04645	0.00703	0.00008	0.00001	**1.4**	**0.1**	21	268	1.4	0.2	1.6	0.2
LTA07-26	1221	2.326	0.00094	0.00046	0.00020	0.00001	0.03387	0.01507	0.00007	0.00001	**1.3**	**0.1**	-120	660	1.0	0.5	1.4	0.2
LTA07-27	549	0.203	9.84759	0.24665	0.45606	0.01000	0.15662	0.00171	0.15770	0.00715	2422	44	***2419***	***19***	2421	23	2960	125
LTA07-28	840	0.290	10.37167	0.24252	0.46576	0.00974	0.16153	0.00165	0.15146	0.00601	2465	43	***2472***	***15***	2469	22	2851	105
LTA07-29	142	0.667	7.46430	0.38127	0.40681	0.01041	0.13308	0.00418	0.11541	0.00277	2200	48	***2139***	***48***	2169	46	2208	50

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

Table 3. (Continued)

			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**	**$^{206}Pb/^{238}U$**	**± 1 s**	**$^{207}Pb/^{206}Pb$**	**± 1 s**	**$^{207}Pb/^{235}U$**	**± 1 s**	**$^{208}Pb/^{232}Th$**	**± 1 s**
							LTA-07 (Niutzushan volc. breccia)											
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	0.00009	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)																		
							LTS-01 (beach sand)											
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)																		

Table 3. (Continued)

			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**	**^{206}Pb/^{238}U**	**± 1 s**	**^{207}Pb/^{206}Pb**	**± 1 s**	**^{207}Pb/^{235}U**	**± 1 s**	**^{208}Pb/^{232}Th**	**± 1 s**
								LTS-01 (beach sand)										
LTS01-07	1002	1.087	0.00117	0.00024	0.00018	0.00001	0.04649	0.00821	0.00007	0.00001	**1.2**	**0.1**	23	252	1.2	0.2	1.4	0.2
LTS01-08	700	0.680	0.00132	0.00057	0.00018	0.00001	0.05258	0.02074	0.00006	0.00002	**1.2**	**0.1**	311	761	1.3	0.6	1.2	0.3
LTS01-09	470	1.087	0.00101	0.00136	0.00019	0.00002	0.03900	0.04885	0.00012	0.00001	**1.2**	**0.1**	-349	1242	1.0	1.0	2.4	0.2
LTS01-10	1032	1.389	0.00177	0.00136	0.00017	0.00002	0.07549	0.04951	0.00005	0.00001	**1.1**	**0.1**	1082	1306	2.0	1.0	1.0	0.2
LTS01-11	361	1.099	0.00295	0.00153	0.00018	0.00002	0.11807	0.04976	0.00008	0.00001	**1.2**	**0.1**	1927	946	3.0	2.0	1.6	0.2
LTS01-12	370	1.333	0.00228	0.00150	0.00018	0.00002	0.09119	0.05107	0.00010	0.00001	**1.2**	**0.1**	1451	1288	2.0	2.0	2.0	0.2
LTS01-13	1010	1.961	0.00103	0.00044	0.00016	0.00001	0.04657	0.01872	0.00006	0.00001	**1.0**	**0.1**	27	636	1.0	0.4	1.3	0.3
LTS01-14	711	1.299	0.00107	0.00080	0.00017	0.00002	0.04648	0.03108	0.00006	0.00001	**1.1**	**0.1**	23	1018	1.1	0.8	1.3	0.3
LTS01-15	919	2.778	0.00038	0.00070	0.00019	0.00001	0.01480	0.02656	0.00007	0.00001	**1.2**	**0.1**	-1044	907	0.4	0.7	1.4	0.2
LTS01-16	519	1.538	0.00133	0.00009	0.00021	0.00001	0.04644	0.00107	0.00010	0.00002	**1.3**	**0.1**	21	47	1.3	0.1	2.0	0.3
LTS01-17	774	2.174	0.00143	0.00067	0.00018	0.00001	0.05626	0.02359	0.00008	0.00001	**1.2**	**0.1**	463	761	1.5	0.7	1.6	0.2
LTS01-18	668	1.087	0.00161	0.00080	0.00018	0.00001	0.06566	0.02939	0.00009	0.00001	**1.2**	**0.1**	796	922	1.6	0.8	1.8	0.2
LTS01-19	409	1.449	0.00126	0.00114	0.00015	0.00001	0.06041	0.05106	0.00004	0.00001	**1.0**	**0.1**	618	1347	1.0	1.0	0.8	0.2
LTS01-20	421	1.250	0.00241	0.00122	0.00023	0.00002	0.07524	0.03233	0.00011	0.00001	**1.5**	**0.1**	1075	888	2.0	1.0	2.2	0.2
LTS01-21	381	0.877	0.00128	0.00033	0.00020	0.00001	0.04623	0.01054	0.00013	0.00003	**1.3**	**0.1**	10	363	1.3	0.3	2.7	0.7
LTS01-22	1183	0.552	0.00022	0.00044	0.00022	0.00001	0.00751	0.01471	0.00008	0.00001	**1.4**	**0.1**	-1488	831	0.2	0.4	1.6	0.2
LTS01-23	748	1.587	0.00037	0.00080	0.00017	0.00001	0.01554	0.03278	0.00005	0.00001	**1.1**	**0.1**	-1002	1028	0.4	0.8	1.0	0.2
LTS01-24	278	0.909	0.00336	0.00200	0.00016	0.00002	0.15215	0.07391	0.00006	0.00002	**1.0**	**0.1**	2370	959	3.0	2.0	1.2	0.4
LTS01-25	397	0.990	0.00083	0.00142	0.00020	0.00002	0.03036	0.04923	0.00003	0.00001	**1.3**	**0.1**	-268	1239	1.0	1.0	0.6	0.2
LTS01-26	1497	1.316	0.00013	0.00035	0.00017	0.00001	0.00562	0.01483	0.00005	0.00001	**1.1**	**0.1**	-1613	928	0.1	0.4	1.0	0.2
LTS01-27	932	1.887	0.00114	0.00038	0.00018	0.00001	0.04672	0.01445	0.00007	0.00001	**1.1**	**0.1**	35	509	1.2	0.4	1.3	0.2
LTS01-28	270	0.980	0.00152	0.00164	0.00020	0.00002	0.05392	0.05338	0.00006	0.00002	**1.3**	**0.1**	368	1353	2.0	2.0	1.2	0.4
LTS01-29	1617	2.222	0.00129	0.00035	0.00020	0.00001	0.04733	0.01076	0.00007	0.00001	**1.3**	**0.1**	66	379	1.3	0.4	1.4	0.2
LTS01-30	1478	1.639	0.00086	0.00031	0.00018	0.00001	0.03486	0.01086	0.00006	0.00001	**1.2**	**0.1**	-79	443	0.9	0.3	1.2	0.2

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

Table 3. (Continued)

			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	$^{206}Pb/^{238}U$	± 1 s	$^{207}Pb/^{206}Pb$	± 1 s	$^{207}Pb/^{235}U$	± 1 s	$^{208}Pb/^{232}Th$	± 1 s
LTS-01 (beach sand)																		
LTS01-31	794	1.136	0.00060	0.00072	0.00020	0.00001	0.02241	0.02589	0.00007	0.00001	**1.3**	**0.1**	-638	898	0.6	0.7	1.4	0.2
LTS01-32	423	1.613	0.00515	0.00225	0.00017	0.00003	0.22294	0.06432	0.00014	0.00002	**1.1**	**0.2**	3002	485	5.0	2.0	2.8	0.4
LTS01-33	1077	1.613	0.00121	0.00025	0.00019	0.00001	0.04678	0.00905	0.00007	0.00001	**1.2**	**0.1**	38	330	1.2	0.3	1.4	0.2
LTS01-34	700	1.299	0.00044	0.00067	0.00018	0.00001	0.01789	0.02635	0.00005	0.00001	**1.2**	**0.1**	-873	932	0.4	0.7	1.0	0.2
LTS01-35	325	1.754	0.00593	0.00285	0.00027	0.00004	0.15980	0.05645	0.00015	0.00002	**1.7**	**0.3**	2454	703	6.0	3.0	3.0	0.4
LTS01-36	325	0.909	0.00114	0.00143	0.00018	0.00002	0.04547	0.05254	0.00004	0.00001	**1.2**	**0.1**	-30	1391	1.0	1.0	0.8	0.2
LTS01-37	588	1.099	0.00127	0.00062	0.00020	0.00001	0.04688	0.02154	0.00007	0.00001	**1.3**	**0.1**	43	786	1.3	0.6	1.4	0.2
LTS01-38	764	1.163	0.00040	0.00063	0.00018	0.00001	0.01637	0.02497	0.00006	0.00001	**1.2**	**0.1**	-956	926	0.4	0.6	1.2	0.2
LTS01-39	2073	1.852	0.00079	0.00023	0.00017	0.00001	0.03449	0.00826	0.00006	0.00001	**1.1**	**0.1**	-94	308	0.8	0.2	1.2	0.2
LTS01-40	494	1.235	0.00019	0.00146	0.00013	0.00002	0.01086	0.08195	0.00004	0.00001	**0.8**	**0.1**	-1276	2194	1.0	1.0	0.8	0.2
LTS01-41	768	1.587	0.00036	0.00080	0.00020	0.00001	0.01334	0.02905	0.00007	0.00001	**1.3**	**0.1**	-1128	980	0.4	0.8	1.4	0.2
LTS01-42	473	1.299	0.00018	0.00149	0.00019	0.00002	0.00672	0.05499	0.00010	0.00001	**1.2**	**0.1**	-1540	1402	1.0	2.0	2.0	0.2
LTS01-43	319	0.971	0.00112	0.00175	0.00018	0.00003	0.04621	0.06558	0.00012	0.00007	**1.1**	**0.2**	9	1488	1.0	2.0	2.0	1.0
LTS01-44	1463	2.857	0.00020	0.00035	0.00019	0.00001	0.00761	0.01296	0.00007	0.00001	**1.2**	**0.1**	-1481	761	0.2	0.4	1.4	0.2
LTS01-45	402	1.563	0.00014	0.00153	0.00018	0.00002	0.00564	0.06107	0.00005	0.00001	**1.2**	**0.1**	-1612	1730	1.0	2.0	1.0	0.2
LTS01-46	797	1.695	0.00134	0.00037	0.00021	0.00001	0.04651	0.01167	0.00007	0.00001	**1.3**	**0.1**	24	425	1.4	0.4	1.5	0.2
LTS01-47	577	1.493	0.00070	0.00077	0.00019	0.00001	0.02625	0.02764	0.00007	0.00001	**1.2**	**0.1**	-453	875	0.7	0.8	1.4	0.2
LTS01-48	303	1.031	0.00407	0.00255	0.00029	0.00004	0.10207	0.05165	0.00017	0.00002	**1.9**	**0.3**	1662	1181	4.0	3.0	3.4	0.4
LTS01-49	574	1.099	0.00183	0.00076	0.00020	0.00001	0.06774	0.02513	0.00007	0.00001	**1.3**	**0.1**	861	771	1.9	0.8	1.4	0.2
LTS01-50	1543	1.205	0.00120	0.00031	0.00017	0.00001	0.05144	0.01065	0.00006	0.00001	**1.1**	**0.1**	261	377	1.2	0.3	1.2	0.2
LTS01-51	355	1.266	0.00042	0.00119	0.00017	0.00002	0.01752	0.04779	0.00005	0.00001	**1.1**	**0.1**	-893	1139	1.0	1.0	1.0	0.2
LTS01-52	216	1.149	0.00039	0.00205	0.00021	0.00002	0.01324	0.06846	0.00013	0.00002	**1.4**	**0.1**	-1134	1630	1.0	2.0	2.6	0.4
LTS01-53	832	1.176	0.00040	0.00053	0.00022	0.00001	0.01308	0.01680	0.00007	0.00001	**1.4**	**0.1**	-1143	810	0.4	0.5	1.4	0.2
LTS01-54	305	1.136	0.00053	0.00174	0.00019	0.00002	0.01997	0.06368	0.00006	0.00001	**1.2**	**0.1**	-763	1469	1.0	2.0	1.2	0.2

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

Table 3. (Continued)

			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**	**$^{206}Pb/^{238}U$**	**± 1 s**	**$^{207}Pb/^{206}Pb$**	**± 1 s**	**$^{207}Pb/^{235}U$**	**± 1 s**	**$^{208}Pb/^{232}Th$**	**± 1 s**
LTS-01 (beach sand)																		
LTS01-55	701	0.568	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	2.326	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	0.787	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	2.128	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	0.901	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 $^{206}Pb/^{238}U$ age = 1.20 ± 0.04 Ma (N = 59, MSWD = 1.8)																		
LTS-02 (river sand)																		
LTS02-01	297	0.617	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	0.535	0.24931	0.00664	0.03584	0.00077	0.05045	0.00060	0.01294	0.00037	***227***	***5***	216	25	226	5	260	7
LTS02-03	355	1.053	0.00112	0.00133	0.00020	0.00002	0.04050	0.04448	0.00007	0.00001	**1.3**	**0.1**	-261	1234	1.0	1.0	1.4	0.2
LTS02-04	334	1.220	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	0.990	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	1.961	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	0.714	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	1.563	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	1.695	0.14298	0.00446	0.01986	0.00043	0.05221	0.00079	0.00686	0.00021	***127***	***3***	295	35	136	4	138	4
LTS02-10	485	1.250	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	0.200	8.75872	0.22735	0.40479	0.00814	0.15693	0.00185	0.11299	0.00225	2191	37	***2423***	***20***	2313	24	2164	41
LTS02-12	329	1.149	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	0.395	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	2.857	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	0.746	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	1.099	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	1.587	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 $^{206}Pb/^{238}U$ age = 1.27 ± 0.09 Ma (N = 15, MSWD = 2.7)																		

Table 3. (Continued)

			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**	**$^{206}Pb/^{238}U$**	**± 1 s**	**$^{207}Pb/^{206}Pb$**	**± 1 s**	**$^{207}Pb/^{235}U$**	**± 1 s**	**$^{208}Pb/^{232}Th$**	**± 1 s**
LTS-02 (river sand)																		
LTS02-18	3696	0.274	0.49135	0.02207	0.06436	0.00132	0.05537	0.00169	0.02007	0.00039	***402***	***8***	427	71	406	15	402	8
LTS02-19	4979	2.000	0.00139	0.00011	0.00024	0.00001	0.04253	0.00193	0.00009	0.00001	**1.5**	**0.1**	-148	93	1.4	0.1	1.8	0.2
LTS02-20	341	1.163	0.00004	0.00232	0.00033	0.00004	0.00081	0.04689	0.00013	0.00002	***2.1***	***0.3***	-1953	1497	1.0	2.0	2.6	0.4
LTS02-21	678	1.124	0.00072	0.00065	0.00023	0.00001	0.02264	0.01956	0.00008	0.00001	**1.5**	**0.1**	-627	774	0.7	0.7	1.6	0.2
LTS02-22	259	1.587	0.29138	0.00734	0.03914	0.00083	0.05400	0.00060	0.01251	0.00036	***248***	***5***	371	24	260	6	251	7
LTS02-23	482	1.408	0.00191	0.00107	0.00017	0.00001	0.08188	0.04159	0.00007	0.00001	**1.1**	**0.1**	1243	1041	2.0	1.0	1.4	0.2
LTS02-24	763	0.806	0.00028	0.00072	0.00020	0.00001	0.01037	0.02620	0.00007	0.00001	**1.3**	**0.1**	-1306	942	0.3	0.7	1.4	0.2
LTS02-25	804	1.449	0.00010	0.00076	0.00018	0.00001	0.00400	0.03020	0.00005	0.00001	**1.2**	**0.1**	-1724	1201	0.1	0.8	1.0	0.2
LTS02-26	767	0.990	0.00004	0.00054	0.00019	0.00001	0.00149	0.02004	0.00005	0.00001	**1.2**	**0.1**	-1903	1189	1.0	0.5	1.0	0.2
LTS02-27	304	0.840	0.00134	0.00143	0.00016	0.00002	0.06110	0.05842	0.00013	0.00002	**1.0**	**0.1**	643	1397	1.0	1.0	2.6	0.4
Mean $^{206}Pb/^{238}U$ age = 1.27 ± 0.09 Ma (N = 15, MSWD = 2.7)																		
LTS-03 (river sand)																		
LTS03-01	494	0.990	0.00388	0.00285	0.00016	0.00003	0.17684	0.09945	0.00004	0.00003	**1.0**	**0.2**	2623	1359	4.0	3.0	0.9	0.7
LTS03-02	546	0.971	0.00124	0.00039	0.00019	0.00001	0.04653	0.01358	0.00007	0.00001	**1.2**	**0.1**	25	416	1.3	0.4	1.5	0.3
LTS03-03	585	1.042	0.00065	0.00083	0.00023	0.00001	0.02053	0.02541	0.00009	0.00001	**1.5**	**0.1**	-734	893	0.7	0.8	1.8	0.2
LTS03-04	2156	1.538	0.00129	0.00067	0.00020	0.00001	0.04717	0.02216	0.00007	0.00001	**1.3**	**0.1**	58	729	1.3	0.7	1.3	0.1
LTS03-05	1196	1.724	0.00127	0.00039	0.00020	0.00001	0.04561	0.01200	0.00007	0.00001	**1.3**	**0.1**	-23	426	1.3	0.4	1.4	0.2
LTS03-06	554	1.149	0.00122	0.00084	0.00019	0.00001	0.04721	0.02994	0.00006	0.00002	**1.2**	**0.1**	60	962	1.2	0.9	1.3	0.3
LTS03-07	1046	0.800	0.00134	0.00055	0.00020	0.00001	0.04750	0.01807	0.00007	0.00001	**1.3**	**0.1**	75	679	1.4	0.6	1.4	0.2
LTS03-08	1249	0.769	0.00020	0.00040	0.00020	0.00001	0.00749	0.01464	0.00007	0.00001	**1.3**	**0.1**	-1489	788	0.2	0.4	1.4	0.2
LTS03-09	812	1.449	0.00137	0.00036	0.00021	0.00001	0.04659	0.01123	0.00007	0.00001	**1.4**	**0.1**	28	397	1.4	0.4	1.5	0.2
LTS03-10	654	1.205	0.00127	0.00078	0.00020	0.00001	0.04635	0.02628	0.00008	0.00002	**1.3**	**0.1**	16	922	1.3	0.8	1.7	0.5
LTS03-11	671	1.370	0.00015	0.00067	0.00019	0.00001	0.00589	0.02603	0.00006	0.00001	**1.2**	**0.1**	-1595	1071	0.2	0.7	1.2	0.2
LTS03-12	974	1.299	0.00154	0.00050	0.00019	0.00001	0.05878	0.01636	0.00006	0.00001	**1.2**	**0.1**	559	570	1.6	0.5	1.2	0.2
Mean $^{206}Pb/^{238}U$ age = 1.28 ± 0.04 Ma (N = 28, MSWD = 1.0)																		

Table 3. (Continued)

			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**	**^{206}Pb/^{238}U**	**± 1 s**	**^{207}Pb/^{206}Pb**	**± 1 s**	**^{207}Pb/^{235}U**	**± 1 s**	**^{208}Pb/^{232}Th**	**± 1 s**
LTS-03 (river sand)																		
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	0.00001	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	306	1.042	0.00049	0.00136	0.00019	0.00002	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	605	1.111	0.00328	0.00167	0.00019	0.00002	0.12548	0.05249	0.00005	0.00001	**1.2**	**0.1**	2036	1128	3.0	2.0	1.1	0.1
LTS03-21	848	1.220	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
LTS03-22	448	1.124	0.00245	0.00095	0.00022	0.00001	0.08188	0.02845	0.00007	0.00001	**1.4**	**0.1**	1243	794	2.5	1.0	1.4	0.2
LTS03-23	813	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	4318	1.667	0.00119	0.00010	0.00019	0.00001	0.04660	0.00265	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}Pb/^{238}U age = 1.28 ± 0.04 Ma (N = 28, MSWD = 1.0)

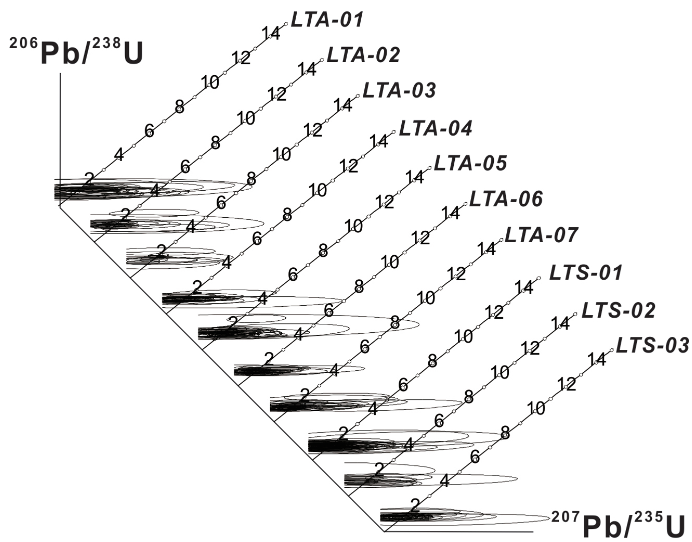

Fig. 7. Concordia diagrams of zircons from the Lutao samples.

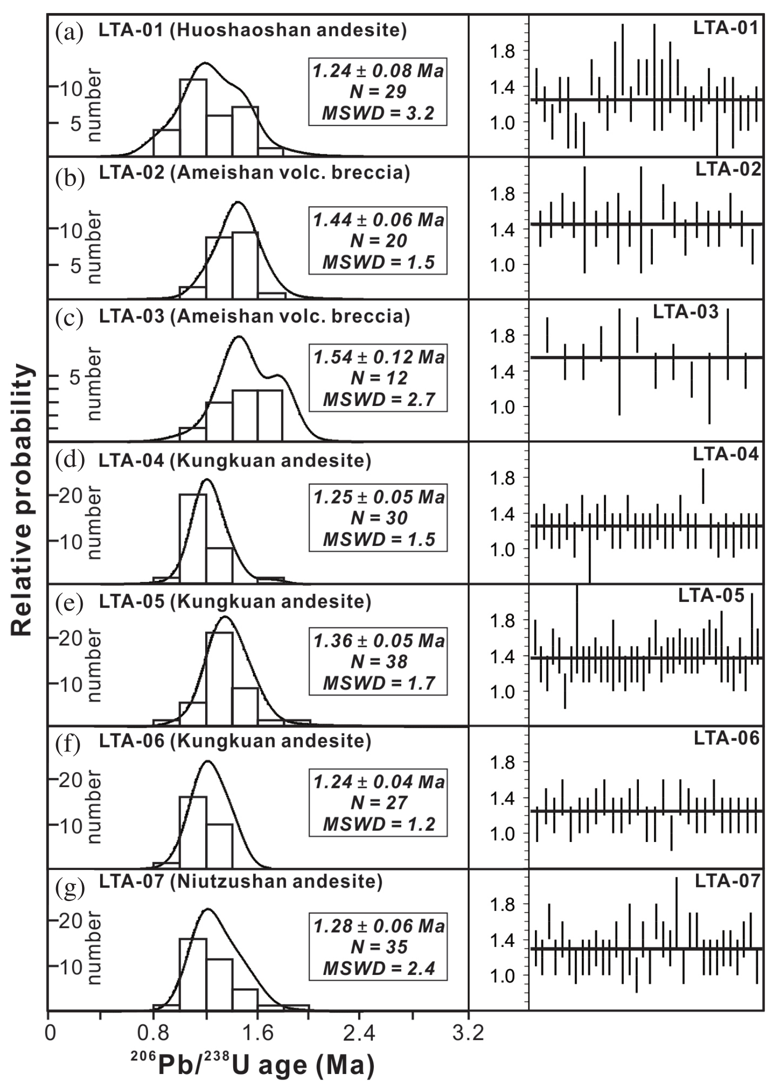

Fig. 8. $^{206}Pb/^{238}U$ age spectra and weighted mean values of Lutao volcanic rocks (a to g) and river/beach sands (h to j). The numerical value (N) denotes the number of zircon grains analyzed and the analytical error bars are 2σ.

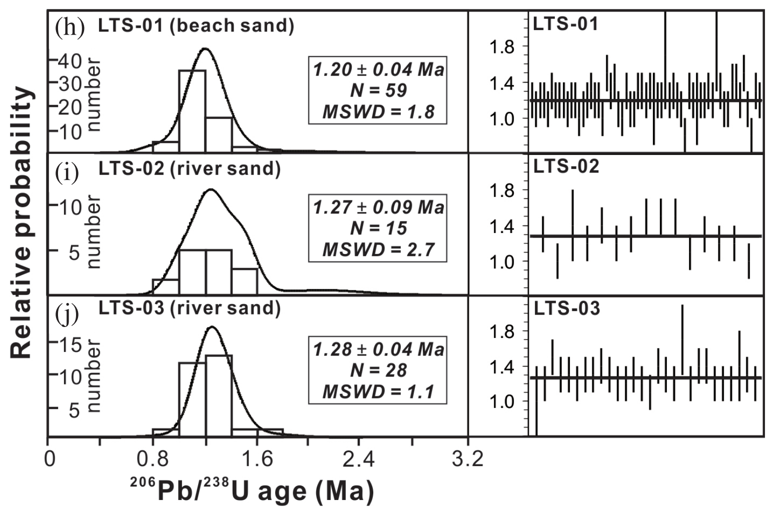

Fig. 8. (Continued)

age of 1.54 ± 0.12 Ma (n = 12; MSWD = 2.7; Fig. 8c). 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 $^{206}Pb/^{238}U$ 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 $^{206}Pb/^{238}U$ 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 $^{206}Pb/^{238}U$ 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 $^{206}Pb/^{238}U$ age of 1.25 ± 0.05 Ma (n = 30; MSWD = 1.5; Fig. 8d), (2) LTA-05 yielding a weighted mean $^{206}Pb/^{238}U$ age of 1.36 ± 0.05 Ma (n = 38; MSWD = 1.7; Fig. 8e), and (3) LTA-06 yielding a weighted mean $^{206}Pb/^{238}U$ 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 $^{206}Pb/^{238}U$ 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 $^{206}Pb/^{238}U$ 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 $^{206}Pb/^{238}U$ 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 $^{206}Pb/^{238}U$ 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 $^{206}Pb/^{238}U$ 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).

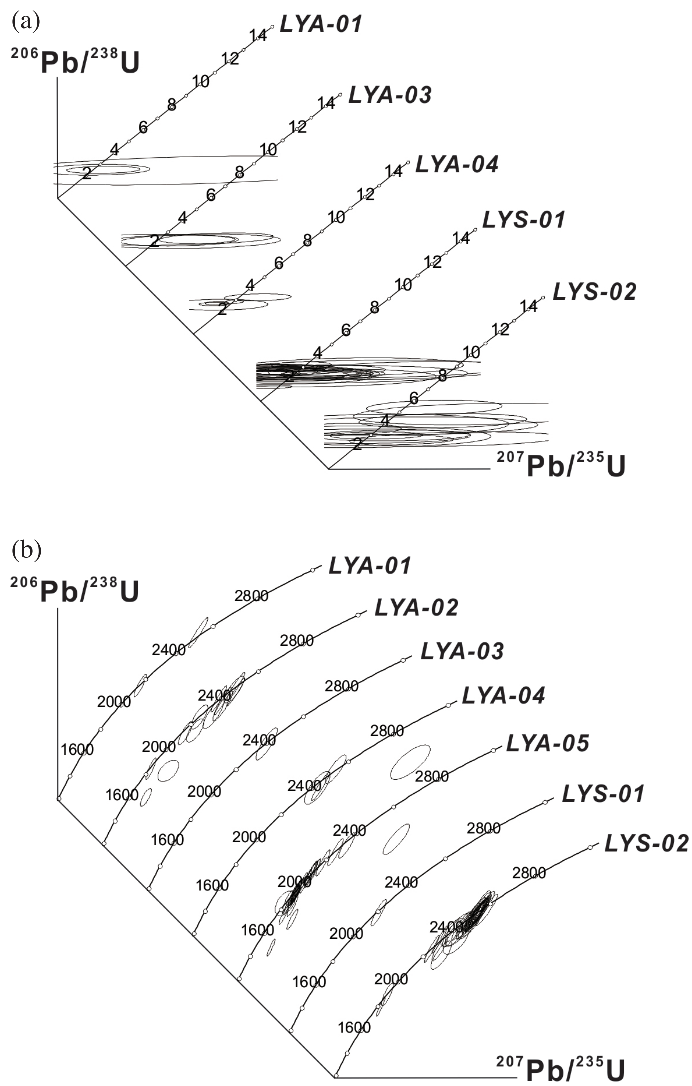

Fig. 9. Concordia diagrams of zircons from the Lanyu samples, separating to (a) young and (b) older populations.

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 $^{206}Pb/^{238}U$ age of 2.35 ± 0.21 Ma (n = 4; 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 ± 0.5 and 7.2 ± 0.5 Ma, respectively, and an additional grain at 14.8 ± 0.6 Ma, interpreted as crystallizing from earlier

Table 4. Zircon U-Pb isotopic data of Lanyu samples.

			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**	**$^{206}Pb/^{238}U$**	**± 1 s**	**$^{207}Pb/^{206}Pb$**	**± 1 s**	**$^{207}Pb/^{235}U$**	**± 1 s**	**$^{208}Pb/^{232}Th$**	**± 1 s**
LYA-01 (Shuangshihyen volc. breccia)																		
LYA01-01	219	1.205	0.00869	0.00546	0.00038	0.00008	0.16532	0.07412	0.00034	0.00005	***2.4***	***0.5***	2511	948	9.0	5.0	7.0	1.0
LYA01-02	346	0.144	7.38010	0.16142	0.39620	0.00781	0.13511	0.00129	0.11391	0.00412	2152	36	***2165***	***16***	2159	20	2180	75
LYA01-03	691	1.010	11.02703	0.24986	0.48585	0.01056	0.16464	0.00164	0.14612	0.00425	2553	46	***2504***	***17***	2525	21	2757	75
LYA01-04	776	0.314	0.21562	0.00508	0.03027	0.00064	0.05167	0.00053	0.01059	0.00030	***192***	***4***	271	25	198	4	213	6
LYA01-05	574	1.515	0.00318	0.00104	0.00039	0.00002	0.05918	0.01668	0.00012	0.00001	***2.5***	***0.1***	574	553	3.0	1.0	2.4	0.2
LYA01-06	181	0.389	0.20671	0.00648	0.02995	0.00065	0.05006	0.00076	0.01029	0.00031	***190***	***4***	198	33	191	5	207	6
LYA01-07	166	0.730	0.10240	0.00453	0.01501	0.00034	0.04949	0.00128	0.00512	0.00016	***96***	***2***	171	63	99	4	103	3
LYA01-08	383	1.538	0.00270	0.00152	0.00039	0.00003	0.05057	0.02503	0.00013	0.00001	***2.5***	***0.2***	221	831	3.0	2.0	2.6	0.2
Mean $^{206}Pb/^{238}U$ age = 2.50 ± 0.17 Ma (N = 3, MSWD = 0.02)																		
LYA-02 (Tungching andesite)																		
LYA02-01	298	0.326	10.54172	0.22960	0.47100	0.00980	0.16235	0.00155	0.14692	0.00433	2488	43	***2480***	***15***	2484	20	2771	76
LYA02-02	223	0.546	5.21934	0.13165	0.33104	0.00750	0.11436	0.00126	0.10488	0.00417	1843	36	***1870***	***20***	1856	21	2016	76
LYA02-03	88	0.571	0.01095	0.00548	0.00112	0.00007	0.07109	0.03164	0.00048	0.00008	***7.2***	***0.5***	960	844	11	6	10	2
LYA02-04	417	0.420	7.99342	0.22458	0.39616	0.00808	0.14631	0.00193	0.11586	0.00765	2151	37	***2303***	***23***	2230	25	2216	139
LYA02-05	415	0.862	0.02300	0.00347	0.00108	0.00007	0.15374	0.01487	0.00040	0.00005	***7.0***	***0.5***	2388	165	23	3	8	1
LYA02-06	398	0.472	9.72517	0.25577	0.43771	0.01041	0.16116	0.00185	0.12915	0.00514	2340	47	***2468***	***21***	2409	24	2455	92
LYA02-07	85	0.538	0.09938	0.00817	0.00953	0.00027	0.07561	0.00439	0.00313	0.00016	***61***	***2***	1085	118	96	8	63	3
LYA02-08	664	0.240	9.72193	0.21833	0.44624	0.00965	0.15802	0.00156	0.13916	0.00402	2379	43	***2435***	***16***	2409	21	2633	71
LYA02-09	205	0.478	9.48144	0.20164	0.44993	0.00917	0.15285	0.00143	0.13876	0.00374	2395	41	***2378***	***16***	2386	20	2626	66
LYA02-10	175	0.649	10.53862	0.22754	0.46195	0.00961	0.16548	0.00157	0.14588	0.00392	2448	42	***2512***	***17***	2483	20	2752	69
LYA02-11	53	1.111	0.08076	0.02003	0.00870	0.00038	0.06731	0.01413	0.00265	0.00008	***56***	***2***	847	439	79	19	54	2
LYA02-12	178	0.524	7.38349	0.17961	0.39183	0.00815	0.13668	0.00146	0.12407	0.00544	2131	38	***2186***	***17***	2159	22	2364	98
LYA02-13	836	0.338	10.44693	0.25521	0.46611	0.00925	0.16258	0.00177	0.12420	0.00631	2466	41	***2483***	***19***	2475	23	2366	113
No magmatic zircon obtained.																		

Table 4. (Continued)

			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**	**^{206}Pb/^{238}U**	**± 1 s**	**^{207}Pb/^{206}Pb**	**± 1 s**	**^{207}Pb/^{235}U**	**± 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	0.00170	0.08061	0.00173	1604	31	***2041***	***24***	1803	24	1567	32
LYA02-16	1466	0.265	9.15173	0.27035	0.42475	0.01046	0.15630	0.00204	0.12185	0.00656	2282	47	***2416***	***21***	2353	27	2324	118
LYA02-17	1170	0.260	6.31083	0.26767	0.32766	0.00744	0.13969	0.00370	0.09251	0.00221	1827	36	***2223***	***42***	2020	37	1788	41
LYA02-18	193	0.990	0.02959	0.00364	0.00230	0.00009	0.09329	0.00834	0.00054	0.00004	***14.8***	***0.6***	1494	173	30	4	10.9	0.8
LYA02-19	238	0.429	8.26416	0.21362	0.41930	0.00848	0.14297	0.00167	0.13384	0.00742	2257	39	***2263***	***19***	2260	23	2539	132
No magmatic zircon obtained.																		
LYA-03 (Lungtouyen volc. breccia)																		
LYA03-01	1502	0.170	9.64836	0.27600	0.45019	0.01120	0.15547	0.00194	0.12793	0.00603	2396	50	***2407***	***22***	2402	26	2433	108
LYA03-02	753	0.893	0.00631	0.00162	0.00038	0.00003	0.11963	0.02238	0.00011	0.00001	**2.5**	**0.2**	1951	373	6.0	2.0	2.2	0.1
LYA03-03	845	1.163	0.00460	0.00253	0.00034	0.00004	0.09791	0.04280	0.00010	0.00001	**2.2**	**0.3**	1585	1110	5.0	3.0	2.0	0.3
LYA03-04	347	0.725	0.00376	0.00167	0.00035	0.00003	0.07752	0.02860	0.00012	0.00002	**2.3**	**0.2**	1135	793	4.0	2.0	2.4	0.4
LYA03-05	173	1.163	0.10524	0.01440	0.01498	0.00043	0.05096	0.00584	0.00472	0.00012	***96***	***3***	239	263	102	13	95	2
LYA03-06	283	0.917	0.00195	0.00232	0.00036	0.00003	0.03916	0.04368	0.00015	0.00002	**2.3**	**0.2**	-339	1242	2.0	2.0	3.0	0.4
LYA03-07	221	1.053	0.13681	0.00463	0.02099	0.00046	0.04728	0.00081	0.00728	0.00021	***134***	***3***	63	38	130	4	147	4
Mean ^{206}Pb/^{238}U age = 2.35 ± 0.21 Ma (N = 4, MSWD = 0.31)																		
LYA-04 (Mantoushan andesite)																		
LYA04-01	2990	0.725	0.23313	0.00537	0.02290	0.00050	0.07385	0.00075	0.00947	0.00028	***146***	***3***	1037	20	213	4	191	6
LYA04-02	475	0.694	0.00171	0.00142	0.00040	0.00003	0.03102	0.02369	0.00019	0.00002	**2.6**	**0.2**	-240	988	2.0	1.0	3.8	0.4
LYA04-03	3402	0.388	0.12940	0.00723	0.02037	0.00046	0.04608	0.00190	0.00655	0.00032	***130***	***3***	2	86	124	6	132	6
LYA04-04	1126	0.752	0.15445	0.00366	0.02307	0.00049	0.04857	0.00050	0.00792	0.00023	***147***	***3***	127	25	146	3	159	5
LYA04-05	7220	0.571	0.19424	0.00436	0.02426	0.00052	0.05808	0.00057	0.00719	0.00022	***155***	***3***	533	22	180	4	145	4
LYA04-06	94	0.422	15.82608	0.51143	0.49580	0.01200	0.23151	0.00320	0.13338	0.00315	2596	52	***3062***	***21***	2866	31	2531	56
LYA04-07	2242	1.449	0.18194	0.00423	0.02296	0.00049	0.05748	0.00058	0.00844	0.00027	***146***	***3***	510	22	170	4	170	5
Mean ^{206}Pb/^{238}U age = 2.72 ± 0.23 Ma (N = 4, MSWD = 1.7)																		

Table 4. (Continued)

			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**	**$^{206}Pb/^{238}U$**	**± 1 s**	**$^{207}Pb/^{206}Pb$**	**± 1 s**	**$^{207}Pb/^{235}U$**	**± 1 s**	**$^{208}Pb/^{232}Th$**	**± 1 s**
LYA-04 (Mantoushan andesite)																		
LYA04-08	2036	2.041	0.00166	0.00033	0.00042	0.00001	0.02849	0.00506	0.00014	0.00001	***2.7***	**0.1**	-351	195	1.7	0.3	2.8	0.2
LYA04-09	636	0.302	3.34970	0.10979	0.18774	0.00394	0.12940	0.00232	0.05341	0.00108	1109	21	***2090***	***33***	1493	26	1052	21
LYA04-10	749	0.588	0.26606	0.03973	0.02197	0.00075	0.08785	0.01082	0.00650	0.00021	***140***	***5***	1379	265	240	32	131	4
LYA04-11	630	1.250	0.00447	0.00095	0.00050	0.00002	0.06442	0.01143	0.00018	0.00001	***3.2***	***0.1***	755	364	4.5	1.0	3.6	0.2
LYA04-12	767	1.515	0.00283	0.00027	0.00044	0.00001	0.04630	0.00348	0.00016	0.00001	***2.9***	**0.1**	13	155	2.9	0.3	3.2	0.2
LYA04-13	1224	2.439	0.00147	0.00043	0.00041	0.00001	0.02583	0.00699	0.00014	0.00001	***2.6***	**0.1**	-473	270	1.5	0.4	2.8	0.2
LYA04-14	254	0.392	11.15109	0.26758	0.48408	0.00987	0.16708	0.00176	0.15624	0.00685	2545	43	***2529***	***19***	2536	22	2934	120
LYA04-15	154	0.267	9.99831	0.32799	0.45223	0.01143	0.16035	0.00218	0.12597	0.00312	2405	51	***2459***	***21***	2435	30	2398	56
LYA04-16	119	0.781	0.12273	0.00604	0.01655	0.00039	0.05380	0.00160	0.00534	0.00017	***106***	***2***	363	65	118	5	108	3
LYA04-17	386	1.408	0.16558	0.00668	0.02388	0.00061	0.05030	0.00104	0.00777	0.00032	***152***	***4***	209	46	156	6	156	6
LYA04-18	628	0.485	10.20987	0.23325	0.45472	0.00994	0.16287	0.00164	0.13936	0.00419	2416	44	***2486***	***17***	2454	21	2637	74
Mean $^{206}Pb/^{238}U$ age = 2.72 ± 0.23 Ma (N = 4, MSWD = 1.7)																		
LYA-05 (Shuangshihyen volc. breccia)																		
LYA05-01	22575	0.305	0.21056	0.01245	0.02384	0.00057	0.06405	0.00277	0.00731	0.00017	***152***	***4***	743	94	194	10	147	3
LYA05-02	429	0.535	8.30807	0.20215	0.41945	0.00946	0.14368	0.00153	0.14272	0.00518	2258	43	***2272***	***18***	2265	22	2697	92
LYA05-03	20669	0.365	0.29245	0.03873	0.02446	0.00081	0.08672	0.00948	0.00725	0.00034	***156***	***5***	1354	222	260	30	146	7
LYA05-04	574	0.909	5.61279	0.13632	0.32794	0.00727	0.12415	0.00131	0.07773	0.00302	1828	35	***2017***	***17***	1918	21	1513	57
LYA05-05	315	0.118	5.69572	0.15301	0.34446	0.00819	0.11994	0.00141	0.17593	0.00779	1908	39	***1955***	***22***	1931	23	3276	134
LYA05-06	657	0.142	5.29615	0.13326	0.33565	0.00768	0.11446	0.00126	0.11943	0.00478	1866	37	***1871***	***18***	1868	21	2280	86
LYA05-07	310	0.361	7.00516	0.15289	0.38804	0.00816	0.13094	0.00126	0.11914	0.00309	2114	38	***2111***	***17***	2112	19	2275	56
LYA05-08	601	0.617	6.19234	0.14883	0.36413	0.00837	0.12335	0.00130	0.09388	0.00287	2002	40	***2005***	***19***	2003	21	1814	53
LYA05-09	696	0.746	6.76723	0.17159	0.38079	0.00903	0.12891	0.00143	0.11745	0.00405	2080	42	***2083***	***20***	2081	22	2245	73
LYA05-10	395	0.833	6.43513	0.15349	0.36991	0.00840	0.12619	0.00132	0.11983	0.00360	2029	40	***2046***	***19***	2037	21	2288	65
No magmatic zircon obtained.																		

Table 4. (Continued)

			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**	**$^{206}Pb/^{238}U$**	**± 1 s**	**$^{207}Pb/^{206}Pb$**	**± 1 s**	**$^{207}Pb/^{235}U$**	**± 1 s**	**$^{208}Pb/^{232}Th$**	**± 1 s**
							LYA-05 (Shuangshihyen volc. breccia)											
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	0.00576	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	0.00169	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	0.00281	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	0.00575	0.00725	0.00017	***147***	***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.

Table 4. (Continued)

Spot	U (ppm)	Th/U	U-Th-Pb ratios								Ages (Ma)							
			$^{207}Pb/^{235}U$	± 1 s	$^{206}Pb/^{238}U$	± 1 s	$^{207}Pb/^{206}Pb$	± 1 s	$^{208}Pb/^{232}Th$	± 1 s	$^{206}Pb/^{238}U$	± 1 s	$^{207}Pb/^{206}Pb$	± 1 s	$^{207}Pb/^{235}U$	± 1 s	$^{208}Pb/^{232}Th$	± 1 s
LYA-05 (Shuangshihyen volc. breccia)																		
LYA05-34	768	0.649	5.95816	0.14018	0.35528	0.00784	0.12165	0.00125	0.11272	0.00359	1960	37	***1981***	***19***	1970	20	2159	65
LYA05-35	14681	0.427	0.38218	0.09039	0.02561	0.00108	0.10821	0.02154	0.00742	0.00056	***163***	***7***	1770	417	329	66	149	11
No magmatic zircon obtained.																		
LYS-01 (river sand)																		
LYS01-01	247	0.800	0.00258	0.00210	0.00035	0.00003	0.05333	0.03934	0.00009	0.00002	**2.3**	**0.2**	343	1106	3.0	2.0	1.8	0.4
LYS01-02	459	1.333	0.00617	0.00324	0.00047	0.00005	0.09529	0.04120	0.00014	0.00001	**3.0**	**0.3**	1534	873	6.0	3.0	2.8	0.3
LYS01-03	204	0.781	0.00270	0.00243	0.00037	0.00003	0.05336	0.04417	0.00017	0.00002	**2.4**	**0.2**	344	1160	3.0	2.0	3.4	0.4
LYS01-04	147	0.709	0.00350	0.00355	0.00032	0.00005	0.07826	0.06946	0.00010	0.00005	**2.1**	**0.3**	1153	1669	4.0	4.0	2.0	1.0
LYS01-05	366	0.704	0.00088	0.00149	0.00042	0.00002	0.01515	0.02500	0.00019	0.00002	**2.7**	**0.1**	-1024	951	1.0	2.0	3.8	0.4
LYS01-06	139	0.735	0.00724	0.00405	0.00044	0.00005	0.11931	0.05486	0.00014	0.00004	**2.8**	**0.3**	1946	1039	7.0	4.0	2.8	0.8
LYS01-07	385	1.010	0.00457	0.00133	0.00037	0.00002	0.09059	0.02206	0.00013	0.00001	**2.4**	**0.1**	1438	551	5.0	1.0	2.6	0.2
LYS01-08	323	0.581	0.00169	0.00154	0.00041	0.00002	0.02995	0.02598	0.00013	0.00002	**2.6**	**0.1**	-286	832	2.0	2.0	2.6	0.4
LYS01-09	211	0.840	0.00177	0.00232	0.00040	0.00003	0.03236	0.04024	0.00011	0.00002	**2.6**	**0.2**	-182	1189	2.0	2.0	2.2	0.4
LYS01-10	256	0.917	0.00395	0.00193	0.00042	0.00003	0.06778	0.02884	0.00026	0.00002	**2.7**	**0.2**	862	874	4.0	2.0	5.3	0.4
LYS01-11	247	0.595	0.00086	0.00201	0.00043	0.00003	0.01455	0.03310	0.00016	0.00003	**2.8**	**0.2**	-1058	1169	1.0	2.0	3.2	0.6
LYS01-12	177	0.877	0.00100	0.00298	0.00037	0.00004	0.01961	0.05654	0.00015	0.00003	**2.4**	**0.3**	-781	1446	1.0	3.0	3.0	0.6
LYS01-13	178	0.820	0.00052	0.00295	0.00033	0.00004	0.01154	0.06421	0.00009	0.00003	**2.1**	**0.3**	-1235	1835	1.0	3.0	1.8	0.6
LYS01-15	699	1.923	0.00226	0.00070	0.00040	0.00002	0.04123	0.01095	0.00014	0.00001	**2.6**	**0.1**	-220	408	2.3	0.7	2.8	0.2
LYS01-16	173	0.629	0.00980	0.00335	0.00042	0.00005	0.16730	0.04113	0.00012	0.00001	**2.7**	**0.3**	2531	460	10	3	2.4	0.2
LYS01-17	199	0.538	7.77377	0.19484	0.40468	0.00916	0.13934	0.00152	0.11937	0.00458	2191	42	***2219***	***19***	2205	23	2279	83
LYS01-18	278	1.010	0.00189	0.00175	0.00036	0.00002	0.03796	0.03326	0.00014	0.00001	**2.3**	**0.1**	-412	1047	2.0	2.0	2.8	0.2
LYS01-19	552	1.333	0.00052	0.00086	0.00037	0.00002	0.00999	0.01604	0.00014	0.00001	**2.4**	**0.1**	-1330	838	0.5	0.9	2.8	0.2
LYS01-20	774	2.041	0.00230	0.00073	0.00045	0.00002	0.03695	0.01027	0.00016	0.00001	**2.9**	**0.1**	-475	452	2.3	0.7	3.2	0.2
Mean $^{206}Pb/^{238}U$ age = 2.63 ± 0.11 Ma (N = 25, MSWD = 4.1)																		

Table 4. (Continued)

			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**	**^{206}Pb/^{238}U**	**± 1 s**	**^{207}Pb/^{206}Pb**	**± 1 s**	**^{207}Pb/^{235}U**	**± 1 s**	**^{208}Pb/^{232}Th**	**± 1 s**
LYS-01 (river sand)																		
LYS01-21	438	0.578	0.00120	0.00110	0.00045	0.00002	0.01910	0.01675	0.00022	0.00002	**2.9**	**0.1**	-808	819	1.0	1.0	4.4	0.4
LYS01-22	114	0.581	0.00369	0.00437	0.00037	0.00005	0.07265	0.07732	0.00016	0.00006	**2.4**	**0.3**	1004	1483	4.0	4.0	3.0	1.0
LYS01-23	172	0.680	0.00114	0.00274	0.00038	0.00003	0.02165	0.05050	0.00012	0.00003	**2.4**	**0.2**	-677	1162	1.0	3.0	2.4	0.6
LYS01-24	197	0.855	0.00076	0.00257	0.00037	0.00003	0.01492	0.04937	0.00014	0.00002	**2.4**	**0.2**	-1037	1498	1.0	3.0	2.8	0.4
LYS01-25	735	2.381	0.00286	0.00085	0.00049	0.00002	0.04231	0.01105	0.00017	0.00001	**3.2**	**0.1**	-160	384	2.9	0.9	3.4	0.2
LYS01-26	610	1.538	0.00057	0.00090	0.00038	0.00002	0.01073	0.01644	0.00012	0.00001	**2.4**	**0.1**	-1284	810	0.6	0.9	2.4	0.2
LYS01-27	367	0.990	0.00145	0.00127	0.00045	0.00002	0.02349	0.01964	0.00013	0.00001	**2.9**	**0.1**	-585	827	1.0	1.0	2.6	0.2
Mean ^{206}Pb/^{238}U age = 2.63 ± 0.11 Ma (N = 25, MSWD = 4.1)																		
LYS-02 (beach sand)																		
LYS02-01	206	0.472	10.86816	0.27436	0.47084	0.01078	0.16743	0.00184	0.13320	0.00477	2487	47	***2532***	***19***	2512	23	2527	85
LYS02-02	136	0.413	11.14621	0.25324	0.48011	0.01025	0.16839	0.00167	0.13816	0.00411	2528	45	***2542***	***17***	2535	21	2616	73
LYS02-03	148	0.450	11.28146	0.27502	0.49203	0.01102	0.16631	0.00177	0.13800	0.00466	2579	48	***2521***	***17***	2547	23	2613	83
LYS02-04	1067	0.508	0.91419	0.07240	0.08775	0.00213	0.07556	0.00480	0.02640	0.00057	***542***	***13***	1083	127	659	38	527	11
LYS02-05	296	0.413	9.79159	0.33232	0.43535	0.00997	0.16312	0.00289	0.12107	0.00268	2330	45	***2488***	***31***	2415	31	2310	48
LYS02-06	189	0.332	10.72898	0.24559	0.47363	0.00977	0.16430	0.00164	0.13822	0.00513	2499	43	***2500***	***18***	2500	21	2617	91
LYS02-07	148	0.488	11.26340	0.25337	0.48395	0.01045	0.16881	0.00167	0.13955	0.00360	2544	45	***2546***	***16***	2545	21	2640	64
LYS02-08	309	0.617	0.00795	0.00238	0.00066	0.00004	0.08800	0.02167	0.00022	0.00003	***4.3***	***0.3***	1382	536	8.0	2.0	4.4	0.6
LYS02-09	195	0.508	11.50657	0.28520	0.49019	0.01128	0.17028	0.00184	0.12784	0.00411	2571	49	***2560***	***17***	2565	23	2432	74
LYS02-10	176	0.549	11.25843	0.24558	0.48213	0.01010	0.16938	0.00163	0.14038	0.00366	2537	44	***2552***	***16***	2545	20	2655	65
LYS02-11	179	0.581	11.41398	0.25216	0.48703	0.01033	0.16999	0.00165	0.14028	0.00364	2558	45	***2558***	***16***	2558	21	2653	65
LYS02-12	124	0.510	11.07507	0.25785	0.47674	0.00999	0.16851	0.00171	0.14116	0.00503	2513	44	***2543***	***17***	2529	22	2669	89
LYS02-13	127	0.256	10.89932	0.24897	0.47458	0.01006	0.16659	0.00166	0.14010	0.00443	2504	44	***2524***	***16***	2515	21	2650	79
LYS02-14	256	1.163	0.00290	0.00237	0.00040	0.00003	0.05263	0.03950	0.00011	0.00002	**2.6**	**0.2**	313	1142	3.0	2.0	2.2	0.4
Mean ^{206}Pb/^{238}U age = 3.05 ± 0.27 Ma (N = 9, MSWD = 3.0)																		

Table 4. (Continued)

			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**	**^{206}Pb/^{238}U**	**± 1 s**	**^{207}Pb/^{206}Pb**	**± 1 s**	**^{207}Pb/^{235}U**	**± 1 s**	**^{208}Pb/^{232}Th**	**± 1 s**
LYS-02 (beach sand)																		
LYS02-15	179	0.336	10.44953	0.26864	0.46215	0.01008	0.16401	0.00185	0.14398	0.00653	2449	44	***2497***	***20***	2475	24	2719	115
LYS02-16	187	0.472	11.29293	0.27450	0.48346	0.01084	0.16944	0.00180	0.13539	0.00453	2542	47	***2552***	***18***	2548	23	2566	81
LYS02-17	192	0.312	8.86860	0.26528	0.40928	0.00988	0.15717	0.00210	0.11146	0.00593	2212	45	***2425***	***21***	2325	27	2136	108
LYS02-18	839	0.267	5.07750	0.11485	0.32199	0.00689	0.11438	0.00113	0.09625	0.00286	1799	34	***1870***	***18***	1832	19	1857	53
LYS02-19	151	0.323	9.63892	0.32887	0.44754	0.00978	0.15621	0.00284	0.12498	0.00269	2384	44	***2415***	***33***	2401	31	2380	48
LYS02-20	152	0.385	10.86052	0.26876	0.46610	0.00994	0.16903	0.00183	0.14092	0.00605	2466	44	***2548***	***20***	2511	23	2665	107
LYS02-21	1217	0.383	5.48661	0.14855	0.34211	0.00776	0.11633	0.00139	0.09409	0.00460	1897	37	***1901***	***23***	1899	23	1818	85
LYS02-22	100	0.264	9.53047	0.23685	0.44626	0.00924	0.15494	0.00170	0.13521	0.00628	2379	41	***2401***	***18***	2390	23	2563	112
LYS02-23	163	0.758	0.00341	0.00373	0.00060	0.00006	0.04127	0.04147	0.00020	0.00004	**3.9**	**0.4**	-217	1278	3.0	4.0	4.0	0.8
LYS02-24	60	0.346	11.29068	0.28195	0.48877	0.01125	0.16759	0.00183	0.14064	0.00450	2565	49	***2534***	***16***	2547	23	2660	80
LYS02-25	611	0.775	8.27838	0.19271	0.42007	0.00934	0.14298	0.00146	0.12621	0.00366	2261	42	***2264***	***17***	2262	21	2402	66
LYS02-26	250	0.364	10.39010	0.23836	0.46033	0.00974	0.16372	0.00164	0.14488	0.00498	2441	43	***2494***	***17***	2470	21	2735	88
LYS02-27	228	0.319	10.97946	0.25287	0.47341	0.01014	0.16823	0.00169	0.14133	0.00462	2498	44	***2540***	***17***	2521	21	2672	82
LYS02-28	210	0.794	0.10726	0.00763	0.00466	0.00019	0.16677	0.00646	0.00102	0.00007	***30***	***1***	2525	67	103	7	21	1
LYS02-29	278	1.064	0.00442	0.00222	0.00046	0.00003	0.06908	0.03070	0.00011	0.00002	**3.0**	**0.2**	901	903	4.0	2.0	2.2	0.4
LYS02-30	691	0.820	1.18263	0.02784	0.12726	0.00280	0.06741	0.00069	0.04034	0.00122	***772***	***16***	850	21	793	13	799	24
LYS02-31	340	0.621	0.00130	0.00154	0.00055	0.00003	0.01716	0.01949	0.00020	0.00002	**3.5**	**0.2**	-912	824	1.0	2.0	4.0	0.4
LYS02-32	160	0.610	0.00527	0.00379	0.00059	0.00005	0.06463	0.04162	0.00033	0.00005	**3.8**	**0.3**	762	1083	5.0	4.0	7.0	1.0
LYS02-33	164	0.541	11.19276	0.26085	0.47841	0.01005	0.16969	0.00172	0.14311	0.00522	2520	44	***2555***	***19***	2539	22	2703	92
LYS02-34	156	0.437	11.00019	0.25829	0.47675	0.01047	0.16736	0.00172	0.13838	0.00450	2513	46	***2531***	***16***	2523	22	2620	80
LYS02-35	151	0.472	11.12420	0.25328	0.48130	0.01030	0.16764	0.00167	0.14178	0.00443	2533	45	***2534***	***15***	2534	21	2680	78
LYS02-36	188	0.338	10.08953	0.23396	0.45833	0.00990	0.15967	0.00162	0.14365	0.00470	2432	44	***2452***	***16***	2443	21	2713	83
LYS02-37	208	0.465	10.66565	0.29848	0.46397	0.01108	0.16675	0.00205	0.13527	0.00668	2457	49	***2525***	***20***	2494	26	2564	119

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

Table 4. (Continued)

			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**	**$^{206}Pb/^{238}U$**	**± 1 s**	**$^{207}Pb/^{206}Pb$**	**± 1 s**	**$^{207}Pb/^{235}U$**	**± 1 s**	**$^{208}Pb/^{232}Th$**	**± 1 s**
								LYS-02 (beach sand)										
LYS02-38	206	0.552	11.02516	0.28487	0.48052	0.01103	0.16642	0.00187	0.13925	0.00588	2530	48	***2522***	***18***	2525	24	2635	104
LYS02-39	355	0.220	8.78107	0.19629	0.42019	0.00828	0.15157	0.00149	0.11769	0.00233	2261	38	***2364***	***17***	2316	20	2249	42
LYS02-40	181	0.935	0.03939	0.00429	0.00183	0.00009	0.15605	0.01063	0.00040	0.00004	***11.8***	***0.6***	2413	106	39	4	8.1	0.8
LYS02-41	231	0.481	9.95284	0.33737	0.45275	0.01140	0.15944	0.00236	0.12619	0.00311	2407	51	***2450***	***26***	2430	31	2402	56
LYS02-42	460	0.870	8.78192	0.19761	0.43585	0.00946	0.14615	0.00145	0.12801	0.00343	2332	42	***2301***	***16***	2316	21	2435	61
LYS02-43	126	0.730	0.06016	0.00700	0.00297	0.00015	0.14710	0.01092	0.00100	0.00009	***19.1***	***1.0***	2312	123	59	7	20	2
LYS02-44	190	0.526	10.96663	0.25649	0.47622	0.01061	0.16706	0.00172	0.13766	0.00413	2511	46	***2528***	***16***	2520	22	2607	73
LYS02-45	201	1.053	0.12879	0.00840	0.00515	0.00020	0.18135	0.00629	0.00081	0.00006	***33.0***	***1.0***	2665	59	123	8	16	1
LYS02-46	170	0.926	0.00141	0.00404	0.00044	0.00006	0.02310	0.06337	0.00016	0.00003	**2.8**	**0.4**	-604	1587	1.0	4.0	3.2	0.6
LYS02-47	158	0.498	11.72639	0.27564	0.48626	0.01081	0.17493	0.00180	0.15629	0.00491	2554	47	***2605***	***16***	2583	22	2935	86
LYS02-48	191	0.855	0.01058	0.00361	0.00075	0.00006	0.10276	0.02790	0.00024	0.00003	***4.8***	***0.4***	1675	544	11	4	4.9	0.6
LYS02-49	160	0.741	0.00239	0.00307	0.00045	0.00004	0.03823	0.04607	0.00015	0.00003	**2.9**	**0.3**	-395	1230	2.0	3.0	3.0	0.6
LYS02-50	399	0.775	0.00336	0.00132	0.00046	0.00002	0.05295	0.01876	0.00016	0.00001	**3.0**	**0.1**	327	645	3.0	1.0	3.2	0.2
LYS02-51	831	0.704	1.34636	0.03356	0.13495	0.00297	0.07237	0.00079	0.04358	0.00172	***816***	***17***	996	23	866	15	862	33
LYS02-52	373	0.469	0.00736	0.00192	0.00084	0.00004	0.06337	0.01388	0.00036	0.00004	***5.4***	***0.3***	721	453	7.0	2.0	7.3	0.8
LYS02-53	199	1.053	0.00882	0.00300	0.00041	0.00004	0.15442	0.03951	0.00013	0.00002	**2.6**	**0.3**	2395	497	9.0	3.0	2.6	0.4

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

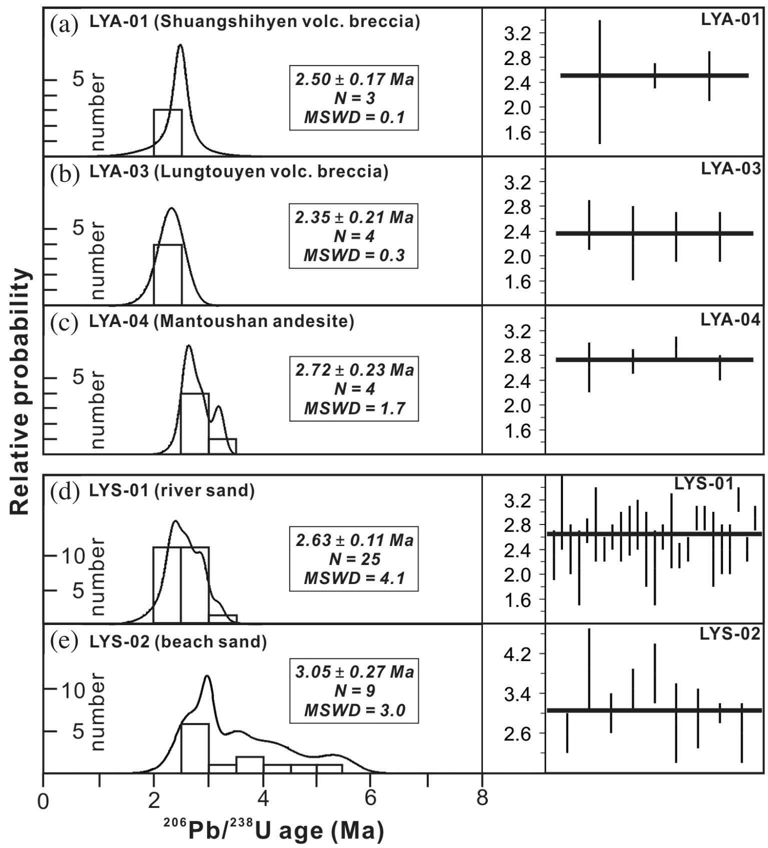

Fig. 10. $^{206}Pb/^{238}U$ age spectra and weighted mean values of Lanyu volcanic rocks (a to c) and sands (d and e). The numerical value (N) denotes the number of zircon grains analyzed and the analytical error bars are 2σ.

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 $^{206}Pb/^{238}U$ age of 2.72 ± 0.23 Ma (n = 4; MSWD = 1.7; Fig. 10c). A fifth grain, with $^{206}Pb/^{238}U$ 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 $^{206}Pb/^{238}U$ 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 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

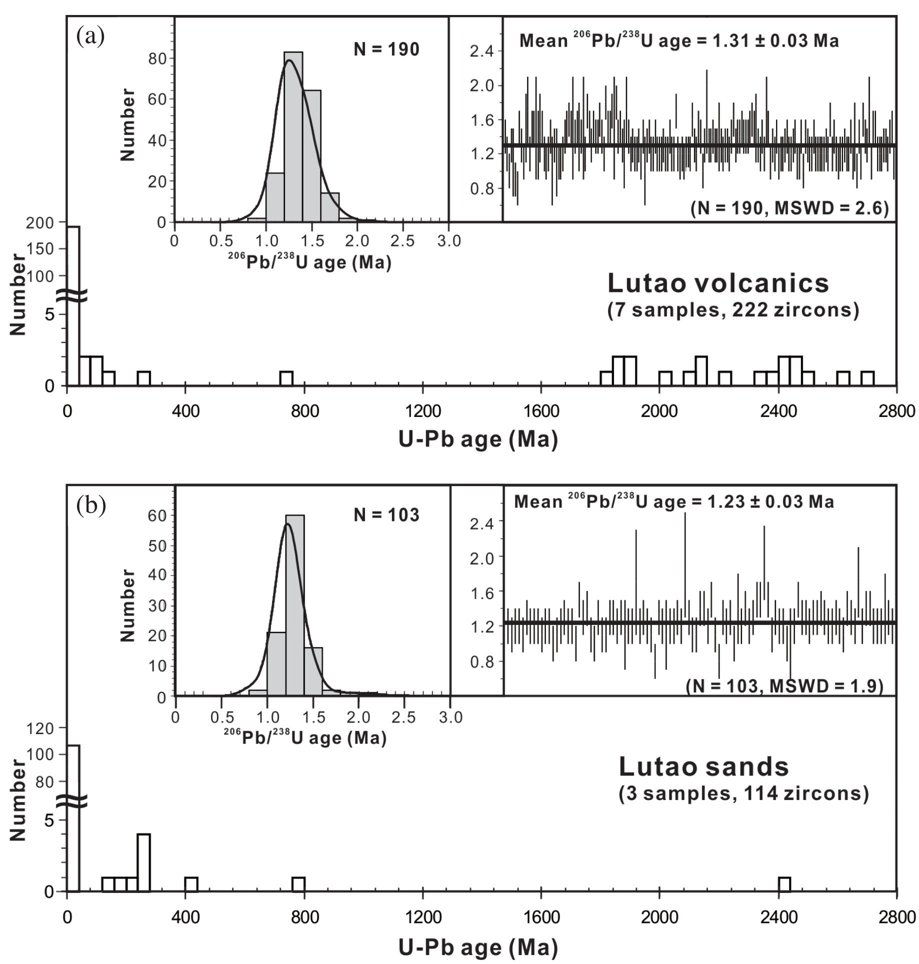

Fig. 11. Collective plots of zircon U-Pb ages from Lutao, (a) volcanic rocks and (b) sands. The numerical value (N) denotes the number of zircon grains analyzed and the analytical error bars are 2σ.

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 $^{206}Pb/^{238}U$ 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 $^{206}Pb/^{238}U$ age of 2.61 ± 0.13 Ma (MSWD = 1.8; Fig. 12a). This mean age coincides with another mean $^{206}Pb/^{238}U$ 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).

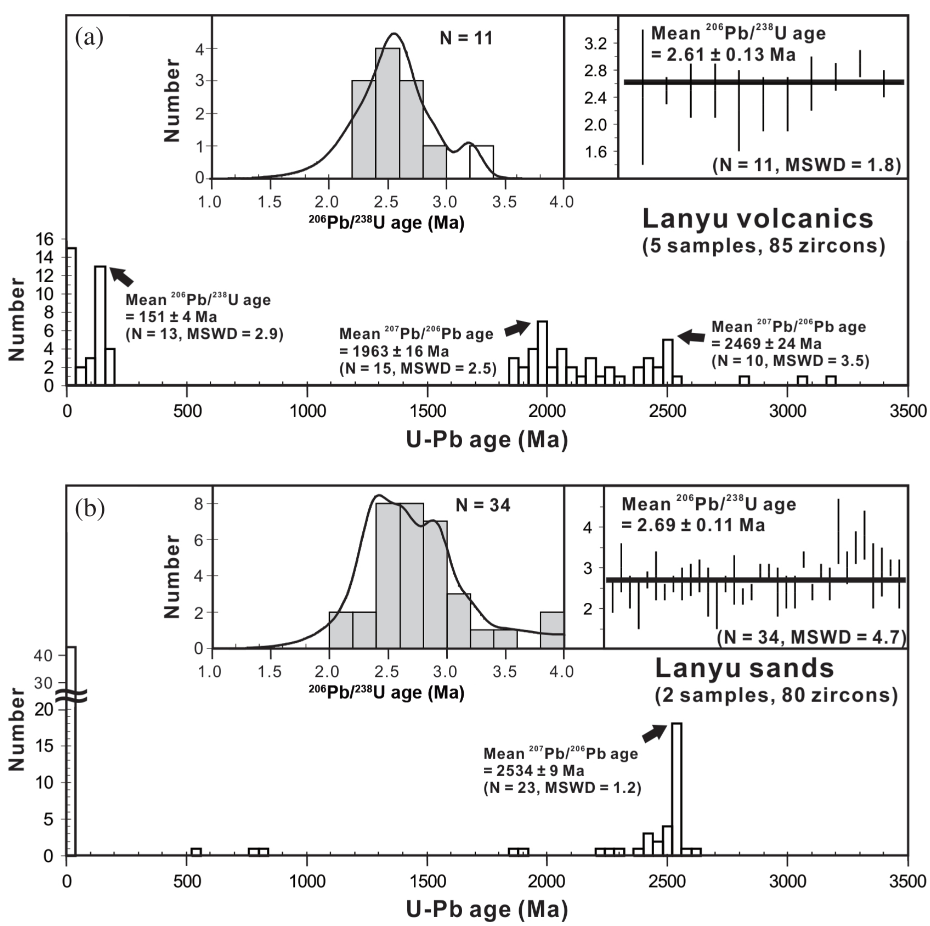

Fig. 12. Collective plots of zircon U-Pb ages from Lanyu (a) volcanic rocks and (b) sands. The numerical value (N) denotes the number of zircon grains analyzed and the analytical error bars are 2σ.

Very abundant older zircons of both inherited or detrital origin are present in Lanyu (Table 4). These include 70 out of a total of 85 grains dated from the volcanic rocks (Fig. 12a) and 46 out of 80 grains from the sand samples (Fig. 12b), with the former yielding primary age clusters at 151 ± 4 Ma (n = 13), 1963 ± 16 Ma (n = 15), and 2469 ± 24 Ma (n = 10), and the latter yielding a large peak at 2534 ± 9 Ma (n = 23). Also, their geologic significance will be discussed in a later section.

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

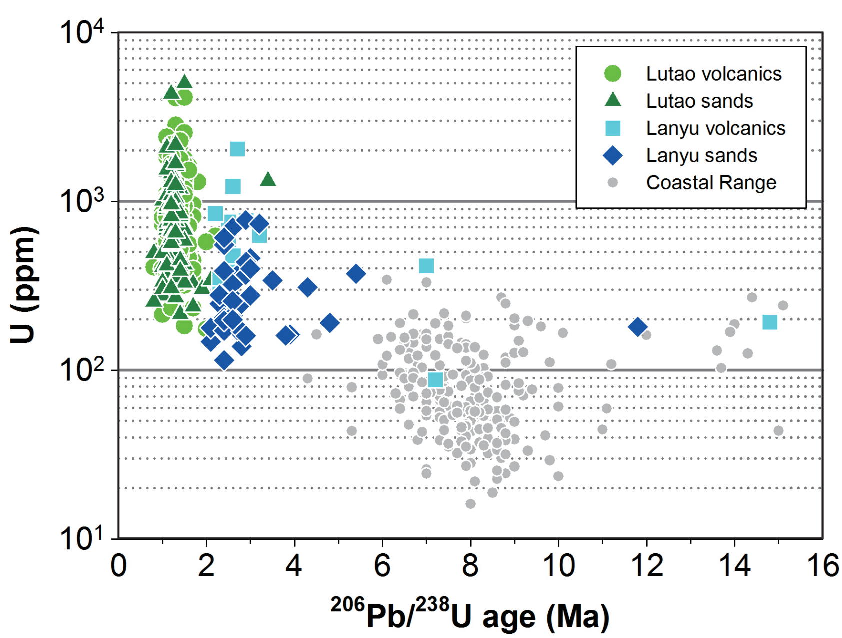

Fig. 13. Plots of U concentrations vs. $^{206}Pb/^{238}U$ ages of magmatic zircons from Lutao and Lanyu, in comparison with those from the Coastal Range. The latter are from our unpublished data.

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 supports to the notion for the existence of a "hidden" continental fragment beneath the northern Luzon magmatic arc.

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