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Emeishan Basalt Ar–Ar overprint ages define several tectonic events that affected the western Yangtze platform in the Mesozoic and Cenozoic[☆]

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Abstract

Ar–Ar whole-rock dating was carried out as part of a detailed stratigraphical investigation of the Emeishan Basalt large igneous province (LIP) in the stratotype area, Sichuan, China. Thirteen (from twenty-one) specimens from three sections yielded reliable reversed isochron and plateau ages (maximum 1σ errors of ≤ 2.1 and 1.6 m.y., respectively), and form two clusters centered on the Late Jurassic–Early Cretaceous and Early–Late Cretaceous, with a tail spanning 82–40 Ma. However, all are appreciably younger than the magnetobiostratigraphically-constrained late Middle Permian (255–260 Ma) age of the basalts, reflecting varying degrees of thermal resetting during the Mesozoic and Cenozoic. Recently, Middle Jurassic–Early Cretaceous ages reported from elsewhere in the LIP have been used to infer a single 40 m.y.-long tectonic episode that affected the western Yangtze Platform. Developing this idea, the new information have been combined with data we hold for other parts of the terrain, and results from three Emeishan LIP Ar–Ar dating studies published during 2002, to give 32 reliable age dates. Three 10–12 m.y. events appear to be recorded in different parts of the province: Middle Jurassic, Late Jurassic–Early Cretaceous and Early–Late Cretaceous, with a fourth shorter middle Eocene episode (the 40 m.y. Mesozoic episode appears to be a sampling artifact). Following a review of the regional deformation/tectonic features, it is argued that activity related to various phases of deformation in the Longmen Shan Thrust Belt is the most likely cause of resetting. The final suturing of the North and South China blocks may have also been responsible for the Middle Jurassic event. However, the Oligocene-present indentation of India into Asia appears not to have had an impact, possibly due to the large-scale related strike-slip faults that have effectively shielded the LIP/Sichuan Basin.

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1. Introduction

The Emeishan Basalt large igneous province (LIP) sits on the western edge of the Yangtze platform (Fig. 1). Over the past decade, a considerable amount of research has been reported from the terrain with a main focus on (i) the

mechanism that generated the LIP (e.g. Luo et al., 1990; Dmitriev and Bogatkov, 1996; Chung and Jahn, 1995; Thompson et al., 2001; Xu et al., 2001), and (ii), the link of the LIP to the two mass extinctions that occurred within 8–10 m.y. of one another in the latter part of the Permian (Zhou et al., 2001, 2002; Ali et al., 2002; Lo et al., 2002). A key aspect of these studies has been establishing the age and duration of volcanism. Regional biostratigraphic studies suggest that the unit is of late Guadalupian (Middle Permian) age (e.g. Sheng and Jin, 1994; Jin and Shang, 2000). Magnetostratigraphic studies (e.g. Huang and Opdyke, 1998) suggest that the bulk of the basalt pile was erupted geologically very quickly; Ali et al. (2002) tie the main part of the lava pile to a single normal polarity field state that terminated about 1 m.y. prior to the end of the Guadalupian.

[☆] Recent U–Pb SHRIMP dating work on Proterozoic rocks exposed in the southwest sector of the Longmen Shan thrust belt ($\sim 101.6^\circ\text{E}$, 28.6°N) has identified 177 ± 3 Ma metamorphic growth rims on zircon crystals associated with movement along a core complex detachment fault (Yan et al., 2003). The new data are consistent with the Middle Jurassic tectonic event proposed herein. In fact, the Middle Jurassic Ar–Ar reset age dates are from the immediately adjacent ‘West of Centre’ portion of the Emeishan LIP.

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Fig. 1. Map showing the areal extent of the Emeishan Basalts (based on Liu and Xu, 1994) and localities mentioned in the text.

Over the past year, the results of several radiometric-dating studies have been reported from the LIP. Possibly the most sensible age (~ 259 Ma) has been obtained from U–Pb SHRIMP studies of zircon grains from intrusive rocks thought to be directly associated with the LIP (Zhou et al., 2001, 2002); the numerical age clearly ties in with a late Guadalupian fossil-age. In terms of direct dating of the Emeishan Basalt flows, several Ar–Ar studies, with varying degrees of success, have been reported (Boven et al., 2002; Lo et al., 2002; Hou et al., 2002). Some results showed a range of formation ages from the end-Middle to late Late Permian (258.9–251.5 Ma), but some others yielded disturbed isotope systematics resulting in Meso-Cenozoic ages. These abnormally young ages have tentatively been interpreted as a result of thermal resetting due to Mesozoic and Cenozoic tectonothermal events (Boven et al., 2002; Lo et al., 2002). Nevertheless, Hou et al. (2002), working on sections in the western and southwestern parts of the LIP, interpreted a series of anomalously young dates (177–135 Ma) to mark a single tectonothermal episode related to the collision of one or more crustal blocks with the western Yangtze platform in the Middle Jurassic–Early Cretaceous.

In a study of sections close to the Emeishan Basalt stratotype area (Fig. 1) a twenty-one aphyric basalt samples were chosen for Ar–Ar whole-rock analysis. The results from these studies, as well as the other recently published results, have a bearing on the cause of the resettings and their possible link to regional tectonic events.

2. Analytical methods

The samples (comprising ~ 2 mm diameter whole-rock chips) were wrapped in aluminum foil packets, stacked in an aluminum canister with three aliquots of the irradiation standard LP-6 biotite (Odin et al., 1982) and irradiated in the VT-C position of the Tsing–Hwa THOR research reactor for 30 h. The neutron flux gradient across the top and bottom of the irradiation canisters was less than 0.9%, as indicated by the variation of J values from the flux monitors. An average value of the J values is adopted in the age calculations.

After irradiation, the samples were loaded into fused-silica boats, and heated with a Lindberg resistance furnace. The released gas was purified with a Ti sponge and two Zr–Al getters, and analyzed with a Varian-MAT GD150 mass spectrometer at the National Taiwan University. Measured isotopic ratios were corrected for the effects of mass discrimination, system blanks, radioactive decays and interfering isotopes produced during irradiation using factors reported by Lo and Lee (1994). Apparent $^{40}\text{Ar}/^{39}\text{Ar}$ ages were calculated from the corrected isotopic ratios using decay constants and isotopic abundance ratios given by Steiger and Jäger (1977). Integrated dates were computed from the sum total of the peak heights, and their errors from the square root of the sum square of the peak-height errors, for all of the temperature steps. Plateau dates were calculated by the same approach, but utilized only those contiguous steps yielding dates, which do not differ at

Table 1

Summary of Ar–Ar data from the Emeishan area in a stratigraphic context. In the Lith. Unit column, F = flow, 12 = flow 12, b/l/m = base/lower/middle. The errors are 1σ values and include uncertainties derived from the age of the irradiation standard. ND = no data

Site	Lith Unit	Ht. in unit (m)	Ht in sec (m)	Integ. Date (Ma)	Error, $\pm$	Rev Isoc. Age (Ma)	Error, $\pm$	Plateau, Date (Ma)	Error, $\pm$
Locality = Xin Chung; Long = $103^\circ 16.466'$; Lat = $29^\circ 17.933'$.									
XC12.2	F-12-m	10	169	147.4	1.6	139.1	2.1	143.3	1.6
XC11.5	F-12-l	2	161	136.4	1.4	ND	ND	ND	ND
XC9.2	F10-m	6	142	92.8	1.0	93.3	1.2	92.9	1.0
XC8.6	F10-l	3	139	70.1	0.8	61.7	0.8	61.2	0.7
XC7.2	F-9-m	10	127	93.4	1.0	95.1	1.4	95.1	1.0
XC4.3	F-8-l	3	98	90.3	0.9	ND	ND	ND	ND
XC3.3	F-7-m	12	73	66.9	0.7	57.3	0.6	56.8	0.6
XC2.3a	F-7-l	5	66	80.2	0.8	77.8	1.2	76.9	0.8
Locality = Ebian; Long = $103^\circ 16.392'$; Lat = $29^\circ 16.139'$.									
EB7.2	F-7-b	2	63	143.1	1.4	146.5	1.8	146.9	1.5
EB6.3	F-6-b	4	59	72.0	0.8	ND	ND	ND	ND
EB5.5a	F-5-b	2	47	96.3	1.0	94.5	1.7	96.7	1.0
EB3.4b	F-3-b	1.5	22.5	99.2	1.0	100.6	1.3	100.9	1.1
EB2.1	F-2-b	2	17	143.3	1.5	140.6	2.5	139.8	1.5
Locality = Qing Yin power station, Emeishan; Long = $103^\circ 24.518'$; Lat = $29^\circ 34.671'$.									
EM34.3	F-12-u	15	265	70.1	0.8	ND	ND	ND	ND
EM27.1	F-12-l	5	255	87.7	0.9	ND	ND	ND	ND
EM26.5a	F-9-m	12	185	173.4	1.9	ND	ND	ND	ND
EM31.2b	F-8-m	12	160	199.7	2.3	ND	ND	ND	ND
EM21.1	F-6-l	1	121	52.7	0.7	53.2	1.1	53.1	0.6
EM20.4	F-5-u	20	115	66.4	0.7	ND	ND	ND	ND
EM17.4	F-3-m	12	55	71.7	0.8	68.9	1.9	70.9	0.8
EM10.4	F-2-u	32	40	43.9	0.5	45.9	1	45.7	0.5

2σ level. In the $^{36}\text{Ar}/^{40}\text{Ar}$ – $^{39}\text{Ar}/^{40}\text{Ar}$ correlation diagrams, the cubic least-squares fitting scheme outlined by York (1969) was employed to regress the data. The regression line yields two intercepts; the inverse of $^{39}\text{Ar}/^{40}\text{Ar}$ intercept produces a so-called intercepted date, whereas the inverse of the $^{36}\text{Ar}/^{40}\text{Ar}$ intercept indicates the composition of a non-radiogenic argon component. One standard deviation, intra-laboratory uncertainties in each apparent age is reported. The analytical data are presented in Supplementary Data Table 1 (age spectra and $^{36}\text{Ar}/^{40}\text{Ar}$ – $^{39}\text{Ar}/^{40}\text{Ar}$ correlation diagrams for each sample are available from JRA). Representative age spectra plots are presented in Fig. 2, and the total data set is summarized in Fig. 3 and Table 1. In selecting samples for geological interpretation only those yielding plateau ages have been used. However, for completeness those samples with only integrated ages are also listed.

3. Results

Three of the eight samples analyzed from the Qing Yin power station section (Table 1, Fig. 1: flank of Mt Emei, Fig. 3) yielded Late Cretaceous-middle Eocene plateau ages (70.9–45.7 Ma). The remaining five samples have a spread of integrated ages from Early Jurassic to terminal Cretaceous. Four of the five samples from the

section near Ebian town (Table 1, Figs. 1 and 3) yielded plateau ages in the range 146.9–96.7 Ma. Two have Late Jurassic/Early Cretaceous ages, but these are physically separated by samples EB3.4b and EB5.5a that yielded ages close to Early/Late Cretaceous boundary. A fifth sample, EB6.3, yielded an integrated age of 72 Ma. At Xin Chung village, eight samples were analyzed from five flows. Plateau ages were obtained from six samples, with ages ranging between Late Jurassic and late Paleocene (143.3–56.8 Ma). Interestingly the two double-sampled flows (Flows 7 and 10) both gave two different ages separated by about 20 m.y. The three samples with integrated ages only gave a similar spread to the plateau-age sample dataset.

In addition to the Emeishan area ages, one author (ChL) had a set of results from eight samples from various parts of the LIP. Unfortunately, only two samples, both from Guizhou Province, yielded reliable plateaus, both with ages around 42 Ma (Table 2). Interestingly, three of the remaining six samples have similar middle Eocene integrated ages, the remaining three samples having ages ranging from the late Early Jurassic to early Eocene.

There appears to be no obvious patterns to the data. None of the Emeishan area sections carry similar ages throughout, and where ages from dual flow samples have been obtained there appear to be discrepancies. However,

Fig. 2. Apparent age spectra of the furnace step-heating analyses for representative samples: a–c are from Xin Chung, d–f are from Ebian, g–i are from the Qing Yin power station. Samples yielding what are considered reliable plateau ages are shown in a,b,d,e,g,h. See Supplementary Data Table 1 for details.

Fig. 3. Stratigraphic summary of the sections in Ebian County and the Mt Emei area with the obtained Ar–Ar at specific levels. Arrows with numbers next to the lithocolumns indicate the plateau age with the error shown in parentheses (also see Table 1). Arrows without numbers indicate sample levels for which a plateau date could not be obtained. Where flows are too poorly exposed to determine their internal structure (colonnades, etc.) they are left blank. Dashed lines indicate that the contact between flows or units is obscured or questionable. While twelve flows are recognized at both Emei and Ebian–Xin Chung, a flow-by-flow correlation is not inferred.

for any sample to yield a reliable, but clearly post formation-age (derived from a plateau and/or reverse isochron age) there has to be some physical basis for its radiometric clock being reset. In fact Hou et al. (2002) recently used a series of Emeishan Basalt reset ages to infer a mid Mesozoic tectonic episode which affected the western Yangtze Platform. Therefore, with three batches of Ar–Ar dates being recently published for the Emeishan

Basalts (Boven et al. 2002; Lo et al. 2002; Hou et al., 2002), together with our large dataset it was thought opportune to evaluate the Hou et al. (2002) model.

4. Summary of other reported data

Other age data obtained from the Emeishan LIP are listed in Table 3. Boven et al. (2002) published the first

Table 2

Summary of previously unpublished Ar–Ar age data obtained by ChL from other parts of the Emeishan LIP. The errors are 1σ values and include uncertainties derived from the age of the irradiation standard. ND = no data

Additional data held by CHL	Integ. Date (Ma)	Error, $\pm$	Plateau, Date (Ma)	Error, $\pm$
Guizhou Prov. EM-QN-04	42.0	1.1	40.2	1.0
Guizhou Prov. EM-QN-04	41.4	1.1	41.4	1.1
Guizhou Prov. EM-QN-18	40.8	1.0	ND	ND
Dongchuan EM-E031	53.3	0.2	ND	ND
Ertan EM-E881	42.2	0.2	ND	ND
Ertan EM-E881	44.2	0.2	ND	ND
Ertan EM-E901	137.4	0.4	ND	ND
East of Ertan EM-E971	181.7	0.5	ND	ND

Ar–Ar dates with variable quality data reported from eleven samples. Using the criteria adopted in our studies, that is well-defined age-spectra plateaus with small associated standard deviations, six samples shown in their Fig. 2 (listed here in Table 3), are considered to yield geologically meaningful data. These include one formation age (254.5 ± 0.2 Ma) and five post-formation age samples. As part of the same study, Hou et al. (2002) presented reverse isochron ages for seven samples from the northern and western parts of the Emeishan LIP. One formation age (258.9 ± 3.4 Ma) was identified along with six Middle Jurassic–Early Cretaceous reset ages (see Table 3). It should also be noted that the

sample-set is based on material from different parts of the LIP, from Mt Emei in the north to close to the Red River Fault near Dali.

Lo et al. (2002) presented a set of formation age dates (254.6–251.5 Ma) for samples from the western part of the LIP (see Table 3). It is noted that the ages are slightly younger than the likely numerical age of the Middle/Late Permian boundary (end of the Guadalupian) or Zhou et al. (2002) U–Pb zircon age data. Several explanations may explain the young dates: (i) volcanism in the western part of the LIP started and terminated in the Late, rather than late Middle, Permian, (ii) there is a problem with the mathematical constants used in the Ar–Ar and/or U–Pb dating systems, thus cross-calibrations lead to apparent errors, (iii) the Ar–Ar dates reflect reset events that occurred a few to several million years after the basalts were erupted.

For illustrating the possible effects of post-formation tectonothermal events, all the available data for the Emeishan LIP are compiled in Fig. 4. As shown in Fig. 4, four age-clusters can be identified: a set of formation age samples at 259–251.5 Ma (1) and reset groups at ± 175 (2), ± 142 (3) and ± 98 Ma (4). The claims for age clustering appear to be bolstered by some of the integrated age sample data, and a possible fifth cluster at 40–45 Ma appears to emerge from the string of ages between 82 and 40 Ma. Aside from the clustering, the data-lows at 250–185, 172–148, 137–104 and 40–0 Ma may also be significant.

Table 3

Summary of the 2002 published Ar–Ar age data from the Emeishan LIP (Boven et al. 2002; Lo et al. 2002; Hou et al., 2002; Zhou et al. 2002). In the 'Part of LIP' column, N = north; WoC = west of center; RR = near Red River Fault

	Rev Isoc. Age (Ma)	Error, $\pm$	Plateau, Date (Ma)	Error, $\pm$	Part of LIP
Selected data from Boven et al. (2002)					
250 m below summit of Mt Emei (Ch-97-05)			82.0	1.0	N
Kangdian High, Longmenshan TB (Ch-97-26)			184.4	2.9	WoC
Xiaguan (Ch-97-90)			254.5	0.2	RR
Ertan Dam (Ch-97-33)			41.6	1.2	WoC
Wuben, nr Panzhihua (Ch-97-48)			103.7	0.6	WoC
Wuben, nr Panzhihua (Ch-97-49)			100.3	1.0	WoC
Data from Hou et al. (2002)					
Panzhihua (R-22)	258.9	3.4			WoC
Lijang (JL-13)	176.9	1.9			WoC
Ertan (R-1)	172.3	2.2			WoC
Binchuan (BH-11) (near Xianguan - see above)	148.2	1.5			RR
Shimian (SH-01)	137.1	3.4			N
Selected data from Lo et al. (2002)					
Ertan (EM-90)	256.2	0.9	251.5	0.9	WoC
Ertan (EM-86)	252.1	1.3	252.8	1.3	WoC
Panzhihua Complex (EM-PZH01)	246.1	1.3	254.6	1.3	WoC
Binchuan (EM-37)	252.0	1.3	252.0	1.3	RR
Maomaogou Complex (EM-MMG05)	252.0	1.3	252.0	1.3	WoC
Panzhihua Complex EM-PZH11	251.6	1.6	251.6	1.6	WoC
U–Pb SHRIMP data from Zhou et al. (2002)					
Xinje Intrusion			259	3	WoC

Fig. 4. Summary of Ar–Ar age data obtained from the Emeishan LIP. (1) The Middle Jurassic–Early Cretaceous tectonic episode of Hou et al. (2002). (2) Shows an age plot in which the samples with plateau/reverse isochron ages are separated into sub-provinces within the LIP (the zircon date of Zhou et al. (2002) is shown as the solid black circle). (3) Shows an age-sample barchart for samples with plateau/reverse isochron ages (tall bars) and integrated ages (for which no plateau or reverse isochrons could be obtained - short bars). (4) Is the geologic time-scale of Palmer and Geissman (1999). (5) Synthesis of regional tectonic events, the broad bars representing distinct events where the timing is tightly constrained. For systems where the age-control is somewhat limited (see text for details) dashed narrow bars are used. J–A and L sutures refers to the Jinshajiang–Ailoshan and Lancangjiang Sutures, F and TB indicates fold and thrust belts (in S. China).

Importantly, they suggest that the Middle Jurassic–Early Cretaceous tectonic episode of Hou et al. (2002) more likely represents two discrete events (Groups 2 and 3) with durations of 10–12 m.y. This is perhaps not surprising. Our knowledge of the individual collision systems in, for example, offshore SE Asia indicates that the activity occurs for a few to 10 m.y. or so, but that the whole region (in effect the orogenic belt) may be active for 50–100 m.y. or even longer (e.g. Hall, 2002).

Another feature to emerge from Fig. 4 is the geographic control on the distribution of ages. For example, the west of center outcrops (triangle between Dali, Panzihua and Muli) and the area near to the Red River Fault are the only places

where formation age dates are preserved. Also, the Middle Jurassic and middle Cretaceous events are recorded only in the west of center and northern parts of the province.

Finally perhaps the most puzzling aspect of the dataset is why do geographically close samples, and often in a single section, record different ages? Hou et al. (2002) imply that if a section was involved in a tectonothermal event, then the whole section would record a similar age. The expanded dataset appears to contradict this, suggesting instead that specific levels within a basalt pile outcrop may be reset at different times or, perhaps more likely, some levels may be reset once, whilst others are reset two or more times, in effect recording the last event.

Fig. 5. (A) Map showing the crustal blocks and sutures of eastern Asia, based on Metcalfe (1999). (B.) more detailed sub-regional structural/tectonic boundary map based on Chen et al. (1995), Chen and Wilson (1996), Wang et al. (1998a) and Boven et al. (2002). The suture numbering scheme used in A has been retained from Metcalfe (1999). Note that several terranes and sutures are not shown, for example 13, Woyle suture. A number of the tectonic features shown in detail in B have also been added. The diamond-shaped shaded areas, black in A and grey in B, mark the approximate geographical extent of the Emeishan LIP (ELIP). Abbreviations KH, Kangdian High; ST, Simao terrane; C-ST Changdu–Simao terrane. Note that the Red River Fault follows the approximate line of the Ailaoashan and Song Ma sutures. In the suture definition key, circled numbers with bars to the left indicate terrane boundaries mentioned in the text.

5. Major adjacent tectonic boundaries

In attempting to understand the distribution of ages, we have looked at East Asia terrane/suture maps (e.g. Metcalfe, 1999; see Fig. 5) and tectonic models that have been proposed for the sub-region (e.g. Chen and Wilson, 1996; Arne et al. 1997; Wang et al., 2000b). A number of tectonic boundaries/zones which, when active, could have reset the Emeishan Basalt radio-isotopic systems were identified. Working from NE of the LIP counter-clockwise, current knowledge of each structure is summarized below. In some cases events are known with a reasonable degree of precision. However, in many cases tectonic phases are constrained only by stratigraphic evidence and the associated error could be 10 or 20 m.y. Dating molasse, continental onlap sequences, erosion surfaces, etc. is notoriously difficult, as can be the problem of establishing the age of a rock unit based on a dated cross-cutting intrusive body.

5.1. Qinling–Dabie suture

Approximately 500 km to the north and northeast of the Emeishan LIP (Fig. 5) is the western part of the Qinling–Dabie suture, marking the boundary between the South and North China Blocks. Combined geological and palaeomagnetic data indicate that suturing commenced in the Permian and involved east to west scissor-like diachronous closure (e.g. Enkin et al., 1992; Zhao et al., 1996). According to Zhao et al. (1996), the blocks had amalgamated before the end of the Middle Jurassic (see also Gilder and Courtillot, 1997; Yokoyama et al., 1999), and might thus explain the reset ages at ~175 Ma.

5.2. Longmen Shan thrust belt

The NE–SW striking Longmen Shan thrust system separates the Songpan–Garze flysch basin (Nie et al. 1994; Chang, 2000) from the stable Yangtze platform to the east (Wang et al. 1998a; Fig. 4). The system is cut by the late Cenozoic Xianshuihe–Xiaojiang strike slip fault (see below). The system could be important for interpreting the Emeishan dates; the northeast thrust belt lies just to the north of the LIP whilst the one to the southwest cuts through the western flank of the LIP. Working on the northeastern belt, Chen and Wilson (1996) identified four periods of activity in the Mesozoic, which they related to discrete phases of magmatism in the Songpan–Garze fold belt at 210–195, 180–170, 160–150 and 140–110 Ma. They also recognized a late Miocene reactivation event. In the southwest, Burchfiel et al. (1995) recognized a young deformation phase affecting ‘upper Eocene(?) Oligocene’ rocks. We suggest that Cenozoic tectonism in this part of the thrust belt could have occurred anytime between the Oligocene and late Miocene, but place a greater emphasis on the younger part of this range, which is reflected in Fig. 4.

5.3. Jinshajiang–Ailoshan and Lancangjiang sutures

East to west, the Jinshajiang–Ailoshan and Lancangjiang sutures separate the South China, Changdu–Simao and Sibumasu Blocks (Fig. 5). The tectonic model of Wang et al. (2000b) provides key information. The Changdu–Simao continent is a narrow fragment that separated from western South China starting in the Late Devonian, akin to SW Japan sitting offshore northeast Asia.

The Changdu–Simao and Sibumasu Blocks sutured first, in the late Middle Triassic, followed by the Late Triassic collision of the composite terrane with South China. Neither event seems to have left its imprint on the Emeishan LIP.

5.4. Red River Fault

The Red River Fault separates the South China and Indochina Blocks. According to [Leloup et al. \(1993, 1995, 2001\)](#) and [Wang et al. \(1998b, 2000a\)](#), the main phase of major shearing was between the Oligocene (32 Ma, possibly even latest Eocene at 36 Ma) and the middle/late Miocene boundary (~16 Ma). From [Fig. 4](#), it appears that movement along the Red River Fault has not led to age resetting of the Emeishan Basalts; the youngest reset age is 40 Ma.

5.5. South China fold and thrust belt

The NE–SW orientated South China fold and thrust belt occurs to the southeast of the Emeishan LIP. [Wang et al. \(1998a\)](#) subdivide the region into three parallel sub-belts. The timing of folding in both the South China Belt sensu stricto and the central South China Fold belt immediately to the northwest cannot be fixed with any precision (middle Mesozoic, [Fig. 4](#)). In the northern sub-belt, Oligo-Miocene activity may have taken place which [Wang et al. \(1998a\)](#) link to the reactivation of the Longmen Shan Thrust Belt.

5.6. Structures within the Emeishan LIP

The study of [Wang et al. \(1998a\)](#) provides a comprehensive review of the Xianshuihe–Xiaojiang Fault and other faults and associated structures that affect the western Yangtze Platform where the Emeishan LIP is exposed. Activity in the region probably extends back to the Oligocene, with younger activity being particularly intense. Thus, the related deformation post-dates the Emeishan LIP reset events.

5.7. Summary

A review of the tectonic phases/structural domains that may have led to the age resetting of the Emeishan Basalts

has eliminated several potential causes and focused attention on one, the Longmen Shan Thrust Belt. The timing of activity seems the most probable cause of all four events, although the final suturing of the North and South China Blocks along the Qinling–Dabie suture could have been responsible for the Middle Jurassic event at around 175 Ma.

6. Conclusion

An apparently complex, and largely post-formational, set of Ar–Ar ages obtained from the Permian Emeishan LIP may in fact provide further insights into the tectonism the western Yangtze platform experienced in the Meso- and Cenozoic. The ages can be used to define three and possibly four resetting events at ~175, ~142, ~98 and ~42 Ma. Based on the known timing of regional tectonic events, it is suggested that movements associated with the Longmen Shan Thrust Belt is the likely cause of overprinting, although final collision of the North and South China blocks in the Middle Jurassic may also be implicated as a cause of the older event.

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Appendix A

Results of $^{40}\text{Ar}/^{39}\text{Ar}$ incremental heating experiments Ebian-Mt Emei area

T (°C)	cum. $^{39}\text{Ar}_K$	Atmos. (%)	$^{36}\text{Ar}/^{39}\text{Ar}$	$^{37}\text{Ar}/^{39}\text{Ar}$	$^{38}\text{Ar}/^{39}\text{Ar}$	$^{40}\text{Ar}/^{39}\text{Ar}$	$^{40}\text{Ar}/^{36}\text{Ar}$	Date (Ma)
EB2-1 Whole Rock ^a								
500	0.005	63.173	0.76438×10^{-1}	0.46787	0.28072×10^{-1}	$0.35728 \times 10^{+2}$	$0.46740 \times 10^{+3}$	70.8 ± 12.0
550	0.016	55.787	0.72487×10^{-1}	0.47341	0.32511×10^{-1}	$0.38360 \times 10^{+2}$	$0.52920 \times 10^{+3}$	90.8 ± 3.8
600	0.042	29.274	0.37972×10^{-1}	0.53733	0.29573×10^{-1}	$0.38221 \times 10^{+2}$	$0.10065 \times 10^{+4}$	142.7 ± 5.6
650	0.095	25.774	0.30872×10^{-1}	0.52676	0.24389×10^{-1}	$0.35270 \times 10^{+2}$	$0.11425 \times 10^{+4}$	138.3 ± 1.9
700	0.173	27.511	0.33021×10^{-1}	0.50200	0.22657×10^{-1}	$0.35359 \times 10^{+2}$	$0.10708 \times 10^{+4}$	135.5 ± 1.7
750	0.257	26.510	0.31517×10^{-1}	0.49133	0.21692×10^{-1}	$0.35020 \times 10^{+2}$	$0.11112 \times 10^{+4}$	136.1 ± 1.8
800	0.352	21.864	0.24976×10^{-1}	0.46592	0.23410×10^{-1}	$0.33624 \times 10^{+2}$	$0.13463 \times 10^{+4}$	138.8 ± 1.6

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<i>T</i> (°C)	cum. $^{39}\text{Ar}_K$	Atmos. (%)	$^{36}\text{Ar}/^{39}\text{Ar}$	$^{37}\text{Ar}/^{39}\text{Ar}$	$^{38}\text{Ar}/^{39}\text{Ar}$	$^{40}\text{Ar}/^{39}\text{Ar}$	$^{40}\text{Ar}/^{36}\text{Ar}$	Date (Ma)
850	0.474	19.639	0.22084×10^{-1}	0.47559	0.29957×10^{-1}	$0.33076 \times 10^{+2}$	$0.14977 \times 10^{+4}$	140.3 ± 1.8
900	0.576	19.847	0.23099×10^{-1}	0.62804	0.35503×10^{-1}	$0.34182 \times 10^{+2}$	$0.14798 \times 10^{+4}$	144.5 ± 1.8
950	0.669	23.360	0.28117×10^{-1}	0.78622	0.38348×10^{-1}	$0.35342 \times 10^{+2}$	$0.12570 \times 10^{+4}$	142.9 ± 1.6
1000	0.749	36.376	0.51156×10^{-1}	$0.12274 \times 10^{+1}$	0.46127×10^{-1}	$0.41331 \times 10^{+2}$	$0.80794 \times 10^{+3}$	139.0 ± 1.6
1050	0.821	49.149	0.86497×10^{-1}	$0.15063 \times 10^{+1}$	0.59899×10^{-1}	$0.51803 \times 10^{+2}$	$0.59890 \times 10^{+3}$	139.3 ± 1.7
1100	0.921	46.914	0.93047×10^{-1}	$0.37656 \times 10^{+1}$	0.64029×10^{-1}	$0.58032 \times 10^{+2}$	$0.62368 \times 10^{+3}$	162.1 ± 2.0
1150	0.976	65.954	0.20478	$0.32795 \times 10^{+1}$	0.86090×10^{-1}	$0.91403 \times 10^{+2}$	$0.44635 \times 10^{+3}$	163.6 ± 2.2
1200	1.000	82.850	0.54436	$0.22708 \times 10^{+1}$	0.15816	$0.19398 \times 10^{+3}$	$0.35634 \times 10^{+3}$	174.3 ± 3.8
EB3-4B Whole Rock ^b								
400	0.024	61.324	0.25544×10^{-1}	0.87179	0.33604×10^{-1}	$0.12230 \times 10^{+2}$	$0.47879 \times 10^{+3}$	25.8 ± 2.5
500	0.067	34.703	0.17961×10^{-1}	0.57948	0.29005×10^{-1}	$0.15197 \times 10^{+2}$	$0.84609 \times 10^{+3}$	53.6 ± 1.1
550	0.108	20.679	0.12286×10^{-1}	0.43478	0.23965×10^{-1}	$0.17428 \times 10^{+2}$	$0.14185 \times 10^{+4}$	74.3 ± 1.2
600	0.138	13.330	0.92118×10^{-2}	0.43355	0.22521×10^{-1}	$0.20205 \times 10^{+2}$	$0.21933 \times 10^{+4}$	93.6 ± 1.9
650	0.160	14.965	0.10861×10^{-1}	0.81649	0.23856×10^{-1}	$0.21063 \times 10^{+2}$	$0.19394 \times 10^{+4}$	95.7 ± 1.4
700	0.220	15.639	0.11893×10^{-1}	0.75456	0.29682×10^{-1}	$0.22137 \times 10^{+2}$	$0.18613 \times 10^{+4}$	99.7 ± 2.0
750	0.274	12.522	0.93508×10^{-2}	0.39446	0.27066×10^{-1}	$0.21858 \times 10^{+2}$	$0.23375 \times 10^{+4}$	102.0 ± 1.7
800	0.361	8.917	0.64243×10^{-2}	0.24031	0.28140×10^{-1}	$0.21114 \times 10^{+2}$	$0.32867 \times 10^{+4}$	102.6 ± 1.8
850	0.497	10.343	0.75839×10^{-2}	0.22736	0.20311×10^{-1}	$0.21531 \times 10^{+2}$	$0.28390 \times 10^{+4}$	102.9 ± 1.1
900	0.612	10.398	0.76009×10^{-2}	0.40984	0.20990×10^{-1}	$0.21332 \times 10^{+2}$	$0.28065 \times 10^{+4}$	102.0 ± 1.1
950	0.738	10.654	0.76691×10^{-2}	0.63485	0.23559×10^{-1}	$0.20850 \times 10^{+2}$	$0.27187 \times 10^{+4}$	99.4 ± 1.1
1000	0.833	18.395	0.14678×10^{-1}	$0.14309 \times 10^{+1}$	0.33638×10^{-1}	$0.23022 \times 10^{+2}$	$0.15685 \times 10^{+4}$	100.3 ± 1.1
1050	0.886	43.208	0.50066×10^{-1}	$0.33251 \times 10^{+1}$	0.76670×10^{-1}	$0.33689 \times 10^{+2}$	$0.67289 \times 10^{+3}$	102.3 ± 1.3
1100	0.946	43.535	0.60643×10^{-1}	$0.61432 \times 10^{+1}$	0.98498×10^{-1}	$0.40128 \times 10^{+2}$	$0.66170 \times 10^{+3}$	120.8 ± 1.5
1150	0.982	60.058	0.13136	$0.22497 \times 10^{+1}$	0.91166×10^{-1}	$0.64380 \times 10^{+2}$	$0.49009 \times 10^{+3}$	136.1 ± 1.8
1200	1.000	81.473	0.38268	$0.12135 \times 10^{+1}$	0.14660	$0.13871 \times 10^{+3}$	$0.36248 \times 10^{+3}$	136.0 ± 3.2
EB5-5a Whole Rock ^c								
400	0.012	3.173	0.12044×10^{-2}	0.44458	0.32825×10^{-1}	$0.10189 \times 10^{+2}$	$0.84597 \times 10^{+4}$	53.3 ± 4.5
500	0.083	30.073	0.13910×10^{-1}	0.31860	0.35382×10^{-1}	$0.13617 \times 10^{+2}$	$0.97895 \times 10^{+3}$	51.5 ± 2.1
550	0.132	23.775	0.12430×10^{-1}	0.25048	0.29661×10^{-1}	$0.15398 \times 10^{+2}$	$0.12388 \times 10^{+4}$	63.2 ± 1.4
600	0.168	9.242	0.57364×10^{-2}	0.25931	0.27528×10^{-1}	$0.18158 \times 10^{+2}$	$0.31653 \times 10^{+4}$	88.2 ± 2.1
650	0.201	13.154	0.88831×10^{-2}	0.29776	0.25471×10^{-1}	$0.19813 \times 10^{+2}$	$0.22304 \times 10^{+4}$	92.0 ± 1.6
700	0.235	11.782	0.83378×10^{-2}	0.23838	0.23581×10^{-1}	$0.20787 \times 10^{+2}$	$0.24932 \times 10^{+4}$	97.9 ± 1.9
750	0.278	10.479	0.71447×10^{-2}	0.18098	0.21101×10^{-1}	$0.20046 \times 10^{+2}$	$0.28057 \times 10^{+4}$	95.9 ± 1.3
800	0.345	8.417	0.56043×10^{-2}	0.14215	0.19698×10^{-1}	$0.19578 \times 10^{+2}$	$0.34933 \times 10^{+4}$	95.8 ± 1.2
850	0.459	9.536	0.63138×10^{-2}	0.13724	0.19238×10^{-1}	$0.19485 \times 10^{+2}$	$0.30861 \times 10^{+4}$	94.2 ± 1.1
900	0.566	9.949	0.67242×10^{-2}	0.22479	0.21728×10^{-1}	$0.19830 \times 10^{+2}$	$0.29491 \times 10^{+4}$	95.4 ± 1.0
950	0.676	9.468	0.64962×10^{-2}	0.30381	0.25781×10^{-1}	$0.20063 \times 10^{+2}$	$0.30884 \times 10^{+4}$	97.0 ± 1.1
1000	0.780	13.020	0.96255×10^{-2}	0.54571	0.32514×10^{-1}	$0.21558 \times 10^{+2}$	$0.22397 \times 10^{+4}$	100.1 ± 1.1
1050	0.838	31.232	0.29127×10^{-1}	0.89500	0.45854×10^{-1}	$0.27371 \times 10^{+2}$	$0.93971 \times 10^{+3}$	100.5 ± 1.2
1100	0.924	28.031	0.31457×10^{-1}	$0.21891 \times 10^{+1}$	0.69089×10^{-1}	$0.32603 \times 10^{+2}$	$0.10364 \times 10^{+4}$	124.6 ± 1.4
1150	0.972	52.839	0.85464×10^{-1}	$0.22429 \times 10^{+1}$	0.92958×10^{-1}	$0.47504 \times 10^{+2}$	$0.55584 \times 10^{+3}$	119.2 ± 1.8
1200	1.000	61.012	0.15859	$0.16171 \times 10^{+1}$	0.11425	$0.76639 \times 10^{+2}$	$0.48326 \times 10^{+3}$	157.2 ± 3.8
EB6-3 Whole Rock ^d								
400	0.109	21.035	0.46286×10^{-2}	0.15200	0.26649×10^{-1}	$0.64766 \times 10^{+1}$	$0.13993 \times 10^{+4}$	27.8 ± 2.2
500	0.157	20.288	0.64303×10^{-2}	0.14991	0.20475×10^{-1}	$0.93388 \times 10^{+1}$	$0.14523 \times 10^{+4}$	40.3 ± 1.0
580	0.255	10.494	0.38029×10^{-2}	0.11739	0.19263×10^{-1}	$0.10653 \times 10^{+2}$	$0.28012 \times 10^{+4}$	51.5 ± 0.8
660	0.323	7.532	0.35315×10^{-2}	0.13835	0.17185×10^{-1}	$0.13746 \times 10^{+2}$	$0.38924 \times 10^{+4}$	68.4 ± 0.9
720	0.376	6.120	0.34554×10^{-2}	0.98781×10^{-1}	0.17147×10^{-1}	$0.16592 \times 10^{+2}$	$0.48017 \times 10^{+4}$	83.5 ± 1.0
780	0.447	7.073	0.42460×10^{-2}	0.74769×10^{-1}	0.19615×10^{-1}	$0.17688 \times 10^{+2}$	$0.41659 \times 10^{+4}$	88.0 ± 1.2
840	0.571	5.393	0.31274×10^{-2}	0.83474×10^{-1}	0.17403×10^{-1}	$0.17048 \times 10^{+2}$	$0.54511 \times 10^{+4}$	86.4 ± 1.0
900	0.705	6.480	0.34882×10^{-2}	0.15404	0.18126×10^{-1}	$0.15756 \times 10^{+2}$	$0.45171 \times 10^{+4}$	79.1 ± 0.8
980	0.844	11.070	0.55767×10^{-2}	0.35490	0.22342×10^{-1}	$0.14673 \times 10^{+2}$	$0.26312 \times 10^{+4}$	70.2 ± 0.7
1040	0.905	31.988	0.20688×10^{-1}	0.64349	0.37065×10^{-1}	$0.18988 \times 10^{+2}$	$0.91786 \times 10^{+3}$	69.5 ± 0.9
1100	0.948	43.991	0.41604×10^{-1}	$0.13540 \times 10^{+1}$	0.75452×10^{-1}	$0.27743 \times 10^{+2}$	$0.66684 \times 10^{+3}$	83.4 ± 1.3
1150	0.983	45.594	0.70476×10^{-1}	$0.18181 \times 10^{+1}$	0.10424	$0.45404 \times 10^{+2}$	$0.64426 \times 10^{+3}$	130.9 ± 1.6
1200	1.000	56.943	0.15509	$0.14280 \times 10^{+1}$	0.11833	$0.80322 \times 10^{+2}$	$0.51790 \times 10^{+3}$	180.7 ± 2.2
EB7-2 Whole Rock ^e								
400	0.004	57.233	0.45299×10^{-1}	0.42071	0.92447×10^{-1}	$0.23362 \times 10^{+2}$	$0.51572 \times 10^{+3}$	54.0 ± 4.0
500	0.024	56.058	0.52136×10^{-1}	0.31733	0.58824×10^{-1}	$0.27469 \times 10^{+2}$	$0.52687 \times 10^{+3}$	65.1 ± 2.1
560	0.047	37.544	0.38447×10^{-1}	0.19140	0.38048×10^{-1}	$0.30251 \times 10^{+2}$	$0.78682 \times 10^{+3}$	100.8 ± 1.7
620	0.078	25.692	0.24263×10^{-1}	0.19158	0.33210×10^{-1}	$0.27879 \times 10^{+2}$	$0.11490 \times 10^{+4}$	110.3 ± 1.7
680	0.114	14.677	0.14968×10^{-1}	0.15938	0.25340×10^{-1}	$0.30084 \times 10^{+2}$	$0.20098 \times 10^{+4}$	135.7 ± 1.6
740	0.159	9.880	0.10494×10^{-1}	0.11896	0.20128×10^{-1}	$0.31324 \times 10^{+2}$	$0.29849 \times 10^{+4}$	148.7 ± 1.6
800	0.235	9.781	0.10180×10^{-1}	0.94032×10^{-1}	0.18726×10^{-1}	$0.30712 \times 10^{+2}$	$0.30168 \times 10^{+4}$	146.0 ± 1.5
860	0.367	6.603	0.68519×10^{-2}	0.85574×10^{-1}	0.18127×10^{-1}	$0.30597 \times 10^{+2}$	$0.44655 \times 10^{+4}$	150.4 ± 1.5
920	0.510	5.378	0.54080×10^{-2}	0.11140	0.21787×10^{-1}	$0.29589 \times 10^{+2}$	$0.54714 \times 10^{+4}$	147.5 ± 1.5

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<i>T</i> (°C)	cum. $^{39}\text{Ar}/\text{K}$	Atmos. (%)	$^{36}\text{Ar}/^{39}\text{Ar}$	$^{37}\text{Ar}/^{39}\text{Ar}$	$^{38}\text{Ar}/^{39}\text{Ar}$	$^{40}\text{Ar}/^{39}\text{Ar}$	$^{40}\text{Ar}/^{36}\text{Ar}$	Date (Ma)
980	0.675	8.191	0.83134×10^{-2}	0.16815	0.24179×10^{-1}	$0.29866 \times 10^{+2}$	$0.35925 \times 10^{+4}$	144.6 ± 1.5
1040	0.762	10.887	0.11715×10^{-1}	0.26153	0.29479×10^{-1}	$0.31644 \times 10^{+2}$	$0.27011 \times 10^{+4}$	148.5 ± 1.5
1100	0.921	12.565	0.13436×10^{-1}	0.67792	0.42378×10^{-1}	$0.31220 \times 10^{+2}$	$0.23236 \times 10^{+4}$	144.0 ± 1.5
1150	0.983	30.656	0.42830×10^{-1}	0.94208	0.68851×10^{-1}	$0.41082 \times 10^{+2}$	$0.95918 \times 10^{+3}$	150.1 ± 1.6
1200	1.000	56.045	0.15743	0.92684	0.11077	$0.82910 \times 10^{+2}$	$0.52664 \times 10^{+3}$	189.9 ± 2.5
EM10-4 Whole Rock ^f								
500	0.017	45.270	0.20241×10^{-1}	0.24262	0.42258×10^{-1}	$0.13200 \times 10^{+2}$	$0.65217 \times 10^{+3}$	39.2 ± 3.1
580	0.034	42.075	0.20343×10^{-1}	0.21298	0.33244×10^{-1}	$0.14278 \times 10^{+2}$	$0.70185 \times 10^{+3}$	44.8 ± 0.8
660	0.082	40.995	0.14911×10^{-1}	0.17734	0.34077×10^{-1}	$0.10744 \times 10^{+2}$	$0.72056 \times 10^{+3}$	34.4 ± 0.7
720	0.175	26.608	0.82415×10^{-2}	0.11963	0.27445×10^{-1}	$0.91477 \times 10^{+1}$	$0.11100 \times 10^{+4}$	36.4 ± 0.5
720	0.267	26.608	0.82415×10^{-2}	0.11963	0.27445×10^{-1}	$0.91477 \times 10^{+1}$	$0.11100 \times 10^{+4}$	36.4 ± 0.5
780	0.368	19.708	0.72507×10^{-2}	0.99667×10^{-1}	0.26202×10^{-1}	$0.10862 \times 10^{+2}$	$0.14981 \times 10^{+4}$	47.2 ± 0.6
860	0.508	28.615	0.11902×10^{-1}	0.10835	0.24298×10^{-1}	$0.12292 \times 10^{+2}$	$0.10327 \times 10^{+4}$	47.5 ± 0.5
910	0.625	24.205	0.92222×10^{-2}	0.14417	0.25904×10^{-1}	$0.11243 \times 10^{+2}$	$0.12191 \times 10^{+4}$	46.1 ± 0.5
950	0.739	22.102	0.78823×10^{-2}	0.18228	0.26980×10^{-1}	$0.10505 \times 10^{+2}$	$0.13328 \times 10^{+4}$	44.3 ± 0.5
990	0.828	29.446	0.11442×10^{-1}	0.29630	0.32718×10^{-1}	$0.11435 \times 10^{+2}$	$0.99942 \times 10^{+3}$	43.7 ± 0.5
1030	0.884	35.353	0.15989×10^{-1}	0.30359	0.41573×10^{-1}	$0.13328 \times 10^{+2}$	$0.83359 \times 10^{+3}$	46.6 ± 0.9
1060	0.939	49.496	0.27204×10^{-1}	0.52164	0.48086×10^{-1}	$0.16191 \times 10^{+2}$	$0.59515 \times 10^{+3}$	44.3 ± 0.6
1090	0.968	67.343	0.56756×10^{-1}	$0.14817 \times 10^{+1}$	0.68686×10^{-1}	$0.24767 \times 10^{+2}$	$0.43638 \times 10^{+3}$	43.9 ± 0.6
1130	0.984	71.146	0.99058×10^{-1}	$0.19958 \times 10^{+1}$	0.10697	$0.40961 \times 10^{+2}$	$0.41350 \times 10^{+3}$	63.8 ± 1.4
1160	0.991	86.586	0.26071	0.79375	0.19064	$0.88935 \times 10^{+2}$	$0.34112 \times 10^{+3}$	64.4 ± 1.7
1200	1.000	87.966	0.27374	$0.12302 \times 10^{+1}$	0.16987	$0.91878 \times 10^{+2}$	$0.33564 \times 10^{+3}$	59.8 ± 2.5
EM17-4 Whole Rock ^g								
400	0.005	33.660	0.24197×10^{-1}	0.37974	0.23718×10^{-1}	$0.21186 \times 10^{+2}$	$0.87556 \times 10^{+3}$	75.5 ± 5.3
500	0.022	73.661	0.60403×10^{-1}	0.39488	0.36254×10^{-1}	$0.24220 \times 10^{+2}$	$0.40097 \times 10^{+3}$	34.7 ± 1.7
600	0.092	47.757	0.28434×10^{-1}	0.31392	0.28358×10^{-1}	$0.17573 \times 10^{+2}$	$0.61802 \times 10^{+3}$	49.7 ± 1.4
660	0.179	24.642	0.12760×10^{-1}	0.24271	0.21780×10^{-1}	$0.15256 \times 10^{+2}$	$0.11956 \times 10^{+4}$	62.0 ± 0.8
720	0.282	18.100	0.95722×10^{-2}	0.20409	0.20282×10^{-1}	$0.15571 \times 10^{+2}$	$0.16267 \times 10^{+4}$	68.6 ± 0.8
780	0.393	17.000	0.91350×10^{-2}	0.19430	0.20530×10^{-1}	$0.15821 \times 10^{+2}$	$0.17319 \times 10^{+4}$	70.6 ± 0.8
840	0.501	17.293	0.93703×10^{-2}	0.21697	0.22981×10^{-1}	$0.15946 \times 10^{+2}$	$0.17017 \times 10^{+4}$	70.9 ± 0.8
900	0.601	17.739	0.98278×10^{-2}	0.29368	0.24597×10^{-1}	$0.16275 \times 10^{+2}$	$0.16561 \times 10^{+4}$	72.0 ± 0.8
950	0.702	22.469	0.12837×10^{-1}	0.38481	0.26631×10^{-1}	$0.16782 \times 10^{+2}$	$0.13073 \times 10^{+4}$	70.0 ± 0.8
1000	0.755	32.492	0.22261×10^{-1}	0.57448	0.34897×10^{-1}	$0.20141 \times 10^{+2}$	$0.90477 \times 10^{+3}$	73.1 ± 1.0
1040	0.838	30.974	0.20555×10^{-1}	0.47773	0.38141×10^{-1}	$0.19522 \times 10^{+2}$	$0.94976 \times 10^{+3}$	72.5 ± 1.6
1080	0.938	28.503	0.23082×10^{-1}	$0.14414 \times 10^{+1}$	0.36661×10^{-1}	$0.23577 \times 10^{+2}$	$0.10215 \times 10^{+4}$	90.3 ± 1.0
1120	0.975	57.340	0.75859×10^{-1}	$0.24334 \times 10^{+1}$	0.56088×10^{-1}	$0.38802 \times 10^{+2}$	$0.51151 \times 10^{+3}$	88.8 ± 1.5
1160	0.992	68.263	0.18185	$0.23555 \times 10^{+1}$	0.98259×10^{-1}	$0.78490 \times 10^{+2}$	$0.43161 \times 10^{+3}$	132.1 ± 2.2
1200	1.000	92.217	0.55123	$0.15627 \times 10^{+1}$	0.17000	$0.17654 \times 10^{+3}$	$0.32026 \times 10^{+3}$	74.0 ± 3.2
EM20-1 Whole Rock ^h								
400	0.013	54.745	0.21362×10^{-1}	0.29040	0.38950×10^{-1}	$0.11519 \times 10^{+2}$	$0.53925 \times 10^{+3}$	28.3 ± 2.2
500	0.029	28.767	0.13431×10^{-1}	0.20402	0.22910×10^{-1}	$0.13772 \times 10^{+2}$	$0.10254 \times 10^{+4}$	53.0 ± 0.8
600	0.090	11.242	0.52027×10^{-2}	0.75834×10^{-1}	0.19227×10^{-1}	$0.13654 \times 10^{+2}$	$0.26243 \times 10^{+4}$	65.2 ± 1.0
660	0.123	13.245	0.65595×10^{-2}	0.68523×10^{-1}	0.26054×10^{-1}	$0.14624 \times 10^{+2}$	$0.22295 \times 10^{+4}$	68.3 ± 1.6
720	0.154	7.708	0.38497×10^{-2}	0.38061×10^{-1}	0.16226×10^{-1}	$0.14750 \times 10^{+2}$	$0.38314 \times 10^{+4}$	73.1 ± 0.9
780	0.195	3.298	0.17599×10^{-2}	0.32986×10^{-1}	0.15929×10^{-1}	$0.15723 \times 10^{+2}$	$0.89341 \times 10^{+4}$	81.5 ± 0.9
840	0.296	3.380	0.18316×10^{-2}	0.32166×10^{-1}	0.15257×10^{-1}	$0.15970 \times 10^{+2}$	$0.87194 \times 10^{+4}$	82.7 ± 0.9
900	0.429	6.204	0.28989×10^{-2}	0.55512×10^{-1}	0.16585×10^{-1}	$0.13770 \times 10^{+2}$	$0.47500 \times 10^{+4}$	69.5 ± 0.7
950	0.585	7.906	0.34301×10^{-2}	0.71021×10^{-1}	0.18192×10^{-1}	$0.12781 \times 10^{+2}$	$0.37262 \times 10^{+4}$	63.4 ± 0.7
1000	0.738	7.461	0.29371×10^{-2}	0.12985	0.19435×10^{-1}	$0.11529 \times 10^{+2}$	$0.39255 \times 10^{+4}$	57.5 ± 0.6
1040	0.830	12.493	0.51225×10^{-2}	0.18778	0.22288×10^{-1}	$0.12032 \times 10^{+2}$	$0.23488 \times 10^{+4}$	56.8 ± 0.6
1080	0.923	22.434	0.10708×10^{-1}	0.32828	0.26064×10^{-1}	$0.14023 \times 10^{+2}$	$0.13096 \times 10^{+4}$	58.7 ± 0.6
1120	0.967	37.625	0.27581×10^{-1}	0.63970	0.33191×10^{-1}	$0.21562 \times 10^{+2}$	$0.78177 \times 10^{+3}$	72.3 ± 0.8
1160	0.993	50.894	0.58293×10^{-1}	0.92800	0.43609×10^{-1}	$0.33737 \times 10^{+2}$	$0.57875 \times 10^{+3}$	88.8 ± 1.3
1200	1.000	77.207	0.26252	0.71772	0.90292×10^{-1}	$0.10044 \times 10^{+3}$	$0.38258 \times 10^{+3}$	121.6 ± 2.5
EM21-1 Whole Rock ⁱ								
400	0.103	21.035	0.46286×10^{-2}	0.15200	0.26649×10^{-1}	$0.64766 \times 10^{+1}$	$0.13993 \times 10^{+4}$	27.8 ± 2.2
500	0.128	45.270	0.20241×10^{-1}	0.24262	0.42258×10^{-1}	$0.13200 \times 10^{+2}$	$0.65217 \times 10^{+3}$	39.2 ± 3.1
600	0.153	35.909	0.17168×10^{-1}	0.29612	0.26893×10^{-1}	$0.14095 \times 10^{+2}$	$0.82098 \times 10^{+3}$	48.9 ± 1.3
660	0.230	27.150	0.10411×10^{-1}	0.22000	0.30376×10^{-1}	$0.11299 \times 10^{+2}$	$0.10853 \times 10^{+4}$	44.6 ± 2.4
720	0.291	18.252	0.65710×10^{-2}	0.17054	0.25561×10^{-1}	$0.10597 \times 10^{+2}$	$0.16127 \times 10^{+4}$	46.9 ± 1.3
780	0.363	13.743	0.55596×10^{-2}	0.13325	0.19425×10^{-1}	$0.11910 \times 10^{+2}$	$0.21422 \times 10^{+4}$	55.4 ± 0.7
840	0.463	17.817	0.74030×10^{-2}	0.13443	0.18521×10^{-1}	$0.12250 \times 10^{+2}$	$0.16547 \times 10^{+4}$	54.4 ± 0.7
900	0.570	15.154	0.59311×10^{-2}	0.19548	0.19043×10^{-1}	$0.11497 \times 10^{+2}$	$0.19383 \times 10^{+4}$	52.7 ± 0.7
950	0.702	10.401	0.38926×10^{-2}	0.23733	0.20159×10^{-1}	$0.10916 \times 10^{+2}$	$0.28042 \times 10^{+4}$	52.8 ± 0.6
1000	0.811	22.216	0.90937×10^{-2}	0.37570	0.27536×10^{-1}	$0.11997 \times 10^{+2}$	$0.13193 \times 10^{+4}$	50.4 ± 1.2
1040	0.864	38.176	0.21022×10^{-1}	0.54056	0.30461×10^{-1}	$0.16193 \times 10^{+2}$	$0.77033 \times 10^{+3}$	54.1 ± 0.7

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<i>T</i> (°C)	cum. $^{39}\text{Ar}_K$	Atmos. (%)	$^{36}\text{Ar}/^{39}\text{Ar}$	$^{37}\text{Ar}/^{39}\text{Ar}$	$^{38}\text{Ar}/^{39}\text{Ar}$	$^{40}\text{Ar}/^{39}\text{Ar}$	$^{40}\text{Ar}/^{36}\text{Ar}$	Date (Ma)
1080	0.941	31.476	0.19376×10^{-1}	$0.10359 \times 10^{+1}$	0.39362×10^{-1}	$0.17971 \times 10^{+2}$	$0.92748 \times 10^{+3}$	66.4 ± 0.7
1120	0.973	54.974	0.60710×10^{-1}	$0.16195 \times 10^{+1}$	0.55978×10^{-1}	$0.32440 \times 10^{+2}$	$0.53434 \times 10^{+3}$	78.5 ± 1.2
1160	0.980	85.607	0.34904	$0.13267 \times 10^{+1}$	0.12160	$0.12039 \times 10^{+3}$	$0.34493 \times 10^{+3}$	92.8 ± 3.7
1200	1.000	63.095	0.14258	$0.17816 \times 10^{+1}$	0.81082×10^{-1}	$0.66591 \times 10^{+2}$	$0.46705 \times 10^{+3}$	130.3 ± 2.7
EM26-5a Whole Rock ^j								
400	0.004	28.929	0.39620×10^{-1}	0.22527	0.81301×10^{-4}	$0.40441 \times 10^{+2}$	$0.10207 \times 10^{+4}$	151.3 ± 29.6
500	0.152	14.313	0.17181×10^{-1}	0.40608	0.26308×10^{-1}	$0.35285 \times 10^{+2}$	$0.20537 \times 10^{+4}$	158.8 ± 2.0
600	0.414	10.213	0.12936×10^{-1}	0.31771	0.29338×10^{-1}	$0.37225 \times 10^{+2}$	$0.28775 \times 10^{+4}$	174.8 ± 2.6
660	0.568	15.475	0.17727×10^{-1}	0.48431	0.39571×10^{-1}	$0.33644 \times 10^{+2}$	$0.18979 \times 10^{+4}$	149.8 ± 2.9
720	0.658	10.634	0.12452×10^{-1}	0.43543	0.34198×10^{-1}	$0.34321 \times 10^{+2}$	$0.27563 \times 10^{+4}$	161.0 ± 2.2
780	0.705	27.042	0.31129×10^{-1}	0.38297	0.43125×10^{-1}	$0.33938 \times 10^{+2}$	$0.10902 \times 10^{+4}$	131.1 ± 3.8
840	0.737	33.815	0.43355×10^{-1}	0.46440	0.62335×10^{-1}	$0.37812 \times 10^{+2}$	$0.87215 \times 10^{+3}$	132.4 ± 4.4
900	0.765	61.006	0.93261×10^{-1}	0.99067	0.10408	$0.45080 \times 10^{+2}$	$0.48337 \times 10^{+3}$	94.1 ± 4.3
950	0.787	55.102	0.11262	$0.20840 \times 10^{+1}$	0.14785	$0.60140 \times 10^{+2}$	$0.53400 \times 10^{+3}$	142.7 ± 6.9
1000	0.809	59.093	0.16048	$0.30688 \times 10^{+1}$	0.18200	$0.79886 \times 10^{+2}$	$0.49780 \times 10^{+3}$	171.4 ± 6.5
1040	0.843	49.818	0.14055	$0.47251 \times 10^{+1}$	0.16489	$0.82682 \times 10^{+2}$	$0.58827 \times 10^{+3}$	215.2 ± 5.2
1080	0.868	77.304	0.34395	$0.70565 \times 10^{+1}$	0.23404	$0.13082 \times 10^{+3}$	$0.38034 \times 10^{+3}$	156.8 ± 6.1
1120	0.892	56.971	0.29621	$0.24882 \times 10^{+1}$	0.21391	$0.15334 \times 10^{+3}$	$0.51767 \times 10^{+3}$	330.7 ± 4.9
1160	0.948	64.916	0.24610	$0.15543 \times 10^{+1}$	0.17094	$0.11187 \times 10^{+3}$	$0.45459 \times 10^{+3}$	203.8 ± 2.5
1200	1.000	60.101	0.28530	$0.13792 \times 10^{+1}$	0.21800	$0.14013 \times 10^{+3}$	$0.49117 \times 10^{+3}$	283.8 ± 3.2
EM27-1 Whole Rock ^k								
400	0.029	27.107	0.77817×10^{-2}	0.18861	0.18075×10^{-1}	$0.84594 \times 10^{+1}$	$0.10871 \times 10^{+4}$	33.5 ± 0.9
500	0.154	12.967	0.52120×10^{-2}	0.18651	0.17470×10^{-1}	$0.11798 \times 10^{+2}$	$0.22636 \times 10^{+4}$	55.4 ± 0.8
600	0.277	8.214	0.45066×10^{-2}	0.13735	0.15845×10^{-1}	$0.16115 \times 10^{+2}$	$0.35759 \times 10^{+4}$	79.3 ± 1.0
660	0.343	9.664	0.57225×10^{-2}	0.16880	0.16819×10^{-1}	$0.17395 \times 10^{+2}$	$0.30398 \times 10^{+4}$	84.2 ± 1.0
720	0.390	7.340	0.48923×10^{-2}	0.17453	0.18457×10^{-1}	$0.19546 \times 10^{+2}$	$0.39953 \times 10^{+4}$	96.7 ± 1.1
780	0.441	3.876	0.27704×10^{-2}	0.16446	0.16871×10^{-1}	$0.20829 \times 10^{+2}$	$0.75184 \times 10^{+4}$	106.6 ± 1.3
840	0.526	7.154	0.49888×10^{-2}	0.15921	0.18253×10^{-1}	$0.20468 \times 10^{+2}$	$0.41027 \times 10^{+4}$	101.4 ± 1.1
900	0.633	9.897	0.63440×10^{-2}	0.24773	0.20769×10^{-1}	$0.18782 \times 10^{+2}$	$0.29606 \times 10^{+4}$	90.5 ± 1.0
950	0.723	15.043	0.99103×10^{-2}	0.33947	0.23585×10^{-1}	$0.19327 \times 10^{+2}$	$0.19502 \times 10^{+4}$	87.9 ± 1.0
1000	0.814	25.806	0.16868×10^{-1}	0.44184	0.27094×10^{-1}	$0.19215 \times 10^{+2}$	$0.11391 \times 10^{+4}$	76.6 ± 0.8
1040	0.861	40.752	0.35921×10^{-1}	0.65103	0.41940×10^{-1}	$0.25956 \times 10^{+2}$	$0.72257 \times 10^{+3}$	82.5 ± 1.1
1080	0.882	43.230	0.71813×10^{-1}	0.66429	0.71968×10^{-1}	$0.49001 \times 10^{+2}$	$0.68234 \times 10^{+3}$	146.7 ± 3.0
1120	0.932	48.361	0.63933×10^{-1}	$0.10212 \times 10^{+1}$	0.76496×10^{-1}	$0.38935 \times 10^{+2}$	$0.60899 \times 10^{+3}$	107.2 ± 1.4
1160	0.969	57.074	0.10881	0.75446	0.77747×10^{-1}	$0.56266 \times 10^{+2}$	$0.51710 \times 10^{+3}$	128.0 ± 2.0
1200	1.000	67.379	0.17599	0.54307	0.87302×10^{-1}	$0.77152 \times 10^{+2}$	$0.43838 \times 10^{+3}$	133.2 ± 2.8
EM31-2b Whole Rock ^l								
400	0.039	25.575	0.35356×10^{-1}	0.28392	0.50590×10^{-1}	$0.40797 \times 10^{+2}$	$0.11539 \times 10^{+4}$	159.5 ± 3.0
500	0.364	16.643	0.23034×10^{-1}	0.19886	0.42442×10^{-1}	$0.40836 \times 10^{+2}$	$0.17729 \times 10^{+4}$	177.8 ± 2.9
600	0.632	11.581	0.17092×10^{-1}	0.11185	0.34859×10^{-1}	$0.43568 \times 10^{+2}$	$0.25490 \times 10^{+4}$	200.0 ± 2.6
660	0.747	10.605	0.14875×10^{-1}	0.14518	0.44178×10^{-1}	$0.41372 \times 10^{+2}$	$0.27814 \times 10^{+4}$	192.4 ± 2.7
720	0.791	36.141	0.42652×10^{-1}	0.21813	0.66008×10^{-1}	$0.34857 \times 10^{+2}$	$0.81724 \times 10^{+3}$	118.2 ± 4.1
780	0.812	46.527	0.51229×10^{-1}	0.34105	0.90648×10^{-1}	$0.32510 \times 10^{+2}$	$0.63460 \times 10^{+3}$	93.0 ± 10.6
840	0.825	76.110	0.11367	0.59464	0.12896	$0.44104 \times 10^{+2}$	$0.38799 \times 10^{+3}$	57.0 ± 16.2
900	0.836	65.596	0.16737	$0.18510 \times 10^{+1}$	0.26413	$0.75215 \times 10^{+2}$	$0.44938 \times 10^{+3}$	136.9 ± 13.8
950	0.849	58.534	0.21187	$0.41032 \times 10^{+1}$	0.32582	$0.10646 \times 10^{+3}$	$0.50248 \times 10^{+3}$	228.1 ± 22.7
1000	0.861	73.365	0.32214	$0.43219 \times 10^{+1}$	0.31947	$0.12933 \times 10^{+3}$	$0.40149 \times 10^{+3}$	180.4 ± 26.2
1040	0.879	71.234	0.35470	$0.80274 \times 10^{+1}$	0.33013	$0.14632 \times 10^{+3}$	$0.41251 \times 10^{+3}$	218.6 ± 11.5
1080	0.901	55.380	0.33161	$0.57913 \times 10^{+1}$	0.33540	$0.17618 \times 10^{+3}$	$0.53129 \times 10^{+3}$	388.4 ± 7.9
1120	0.918	82.653	0.83551	$0.36137 \times 10^{+1}$	0.43492	$0.29841 \times 10^{+3}$	$0.35716 \times 10^{+3}$	264.6 ± 17.5
1160	0.969	62.626	0.36227	$0.32504 \times 10^{+1}$	0.36220	$0.17057 \times 10^{+3}$	$0.47084 \times 10^{+3}$	320.6 ± 6.1
1200	1.000	77.465	0.84208	$0.31334 \times 10^{+1}$	0.58363	$0.32094 \times 10^{+3}$	$0.38113 \times 10^{+3}$	359.7 ± 6.1
EM34-3 Whole Rock ^m								
400	0.017	11.575	0.16550×10^{-1}	0.56872	0.48745×10^{-1}	$0.41909 \times 10^{+2}$	$0.25323 \times 10^{+4}$	192.8 ± 10.1
500	0.237	19.046	0.20330×10^{-1}	0.31229	0.72969×10^{-1}	$0.31447 \times 10^{+2}$	$0.15468 \times 10^{+4}$	134.6 ± 10.9
600	0.472	9.153	0.10487×10^{-1}	0.17681	0.44282×10^{-1}	$0.33742 \times 10^{+2}$	$0.32174 \times 10^{+4}$	160.9 ± 3.8
660	0.561	15.546	0.15898×10^{-1}	0.27163	0.61193×10^{-1}	$0.30116 \times 10^{+2}$	$0.18944 \times 10^{+4}$	134.5 ± 3.0
720	0.601	41.593	0.36783×10^{-1}	0.28623	0.75860×10^{-1}	$0.26109 \times 10^{+2}$	$0.70982 \times 10^{+3}$	81.8 ± 4.6
780	0.627	85.431	0.62870×10^{-1}	0.31958	0.12366	$0.21747 \times 10^{+2}$	$0.34590 \times 10^{+3}$	17.3 ± 7.1
900	0.657	75.424	0.98135×10^{-1}	$0.12070 \times 10^{+1}$	0.23935	$0.38356 \times 10^{+2}$	$0.39085 \times 10^{+3}$	51.1 ± 5.1
1000	0.696	72.613	0.16130	$0.35738 \times 10^{+1}$	0.26393	$0.65301 \times 10^{+2}$	$0.40483 \times 10^{+3}$	95.8 ± 3.2
1060	0.758	49.111	0.13616	$0.47333 \times 10^{+1}$	0.23763	$0.81227 \times 10^{+2}$	$0.59657 \times 10^{+3}$	214.4 ± 3.8
1140	0.864	56.568	0.14124	$0.15305 \times 10^{+1}$	0.15869	$0.73603 \times 10^{+2}$	$0.52114 \times 10^{+3}$	167.7 ± 3.1
1200	1.000	57.194	0.16124	$0.10549 \times 10^{+1}$	0.14813	$0.83198 \times 10^{+2}$	$0.51598 \times 10^{+3}$	185.8 ± 2.3

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<i>T</i> (°C)	cum. $^{39}\text{Ar}_\text{K}$	Atmos. (%)	$^{36}\text{Ar}/^{39}\text{Ar}$	$^{37}\text{Ar}/^{39}\text{Ar}$	$^{38}\text{Ar}/^{39}\text{Ar}$	$^{40}\text{Ar}/^{39}\text{Ar}$	$^{40}\text{Ar}/^{36}\text{Ar}$	Date (Ma)
XC11-5 Whole Rock ⁿ								
600	0.107	25.092	0.14867×10^{-1}	0.16106	0.38163×10^{-1}	$0.17489 \times 10^{+2}$	$0.11763 \times 10^{+4}$	70.5 ± 2.5
660	0.267	7.778	0.95830×10^{-2}	0.73028×10^{-1}	0.22807×10^{-1}	$0.36365 \times 10^{+2}$	$0.37947 \times 10^{+4}$	175.3 ± 2.1
720	0.318	11.376	0.12919×10^{-1}	0.98562×10^{-1}	0.25968×10^{-1}	$0.33520 \times 10^{+2}$	$0.25947 \times 10^{+4}$	156.1 ± 2.1
780	0.360	12.832	0.13740×10^{-1}	0.12269	0.27162×10^{-1}	$0.31597 \times 10^{+2}$	$0.22997 \times 10^{+4}$	145.2 ± 1.8
840	0.437	15.195	0.15746×10^{-1}	0.12451	0.29020×10^{-1}	$0.30589 \times 10^{+2}$	$0.19426 \times 10^{+4}$	137.0 ± 1.7
900	0.542	23.009	0.23831×10^{-1}	0.24767	0.33971×10^{-1}	$0.30552 \times 10^{+2}$	$0.12821 \times 10^{+4}$	124.7 ± 1.4
950	0.628	29.494	0.30681×10^{-1}	0.35979	0.41027×10^{-1}	$0.30675 \times 10^{+2}$	$0.99983 \times 10^{+3}$	115.0 ± 1.2
1000	0.717	33.934	0.37329×10^{-1}	0.48493	0.54980×10^{-1}	$0.32428 \times 10^{+2}$	$0.86870 \times 10^{+3}$	114.0 ± 1.3
1040	0.774	38.241	0.52251×10^{-1}	0.78626	0.91791×10^{-1}	$0.40250 \times 10^{+2}$	$0.77032 \times 10^{+3}$	131.6 ± 1.6
1080	0.816	41.699	0.77597×10^{-1}	$0.10027 \times 10^{+1}$	0.14072	$0.54836 \times 10^{+2}$	$0.70668 \times 10^{+3}$	167.6 ± 2.6
1120	0.883	47.226	0.82279×10^{-1}	$0.10936 \times 10^{+1}$	0.13983	$0.51338 \times 10^{+2}$	$0.62395 \times 10^{+3}$	143.0 ± 1.8
1160	0.972	41.790	0.71679×10^{-1}	0.84568	0.14173	$0.50562 \times 10^{+2}$	$0.70539 \times 10^{+3}$	154.8 ± 1.7
1200	1.000	68.641	0.24804	0.69563	0.22797	$0.10674 \times 10^{+3}$	$0.43031 \times 10^{+3}$	175.1 ± 3.4
XC12-2 Whole Rock ^o								
400	0.039	32.305	0.35299×10^{-1}	0.53969	0.12133	$0.32191 \times 10^{+2}$	$0.91195 \times 10^{+3}$	115.8 ± 5.3
500	0.078	20.977	0.22200×10^{-1}	0.44129	0.47502×10^{-1}	$0.31142 \times 10^{+2}$	$0.14028 \times 10^{+4}$	130.3 ± 3.9
600	0.147	22.390	0.26756×10^{-1}	0.24648	0.36122×10^{-1}	$0.35257 \times 10^{+2}$	$0.13177 \times 10^{+4}$	144.3 ± 2.6
660	0.215	24.981	0.31085×10^{-1}	0.35541	0.61217×10^{-1}	$0.36692 \times 10^{+2}$	$0.11804 \times 10^{+4}$	145.1 ± 3.5
720	0.252	22.147	0.24859×10^{-1}	0.30021	0.52044×10^{-1}	$0.33095 \times 10^{+2}$	$0.13313 \times 10^{+4}$	136.2 ± 2.9
780	0.307	16.892	0.18042×10^{-1}	0.20302	0.41410×10^{-1}	$0.31501 \times 10^{+2}$	$0.17460 \times 10^{+4}$	138.3 ± 1.9
840	0.418	16.079	0.17359×10^{-1}	0.17866	0.32847×10^{-1}	$0.31848 \times 10^{+2}$	$0.18346 \times 10^{+4}$	141.1 ± 1.8
900	0.509	23.137	0.26883×10^{-1}	0.48266	0.58894×10^{-1}	$0.34205 \times 10^{+2}$	$0.12724 \times 10^{+4}$	138.9 ± 1.7
950	0.586	27.722	0.36319×10^{-1}	0.78703	0.77396×10^{-1}	$0.38528 \times 10^{+2}$	$0.10608 \times 10^{+4}$	146.8 ± 1.8
1000	0.638	45.035	0.75280×10^{-1}	$0.20387 \times 10^{+1}$	0.12676	$0.49084 \times 10^{+2}$	$0.65201 \times 10^{+3}$	142.5 ± 2.9
1040	0.670	61.084	0.14259	$0.30654 \times 10^{+1}$	0.21735	$0.68629 \times 10^{+2}$	$0.48131 \times 10^{+3}$	141.3 ± 3.6
1080	0.703	63.356	0.16735	$0.15863 \times 10^{+1}$	0.23298	$0.77894 \times 10^{+2}$	$0.46546 \times 10^{+3}$	150.5 ± 3.1
1120	0.761	57.496	0.13331	0.76496	0.16671	$0.68445 \times 10^{+2}$	$0.51341 \times 10^{+3}$	153.1 ± 2.2
1160	0.898	41.988	0.75399×10^{-1}	0.49787	0.13507	$0.53002 \times 10^{+2}$	$0.70296 \times 10^{+3}$	161.4 ± 1.8
1200	1.000	52.677	0.12597	0.41060	0.17107	$0.70636 \times 10^{+2}$	$0.56073 \times 10^{+3}$	174.9 ± 2.0
XC2-3a Whole Rock ^p								
500	0.017	53.660	0.24345×10^{-1}	0.26864	0.49151×10^{-1}	$0.13397 \times 10^{+2}$	$0.55031 \times 10^{+3}$	33.7 ± 2.2
600	0.064	49.644	0.33671×10^{-1}	0.27887	0.41179×10^{-1}	$0.20029 \times 10^{+2}$	$0.59483 \times 10^{+3}$	54.5 ± 1.4
660	0.101	38.025	0.26243×10^{-1}	0.28455	0.27070×10^{-1}	$0.20366 \times 10^{+2}$	$0.77606 \times 10^{+3}$	68.0 ± 1.1
720	0.163	20.784	0.13244×10^{-1}	0.21820	0.22728×10^{-1}	$0.18779 \times 10^{+2}$	$0.14180 \times 10^{+4}$	79.8 ± 0.9
780	0.237	16.982	0.10109×10^{-1}	0.15963	0.21130×10^{-1}	$0.17549 \times 10^{+2}$	$0.17359 \times 10^{+4}$	78.2 ± 0.9
840	0.332	14.142	0.79380×10^{-2}	0.13850	0.19419×10^{-1}	$0.16542 \times 10^{+2}$	$0.20839 \times 10^{+4}$	76.3 ± 0.9
900	0.446	12.009	0.67221×10^{-2}	0.17342	0.22446×10^{-1}	$0.16461 \times 10^{+2}$	$0.24488 \times 10^{+4}$	77.7 ± 0.9
950	0.602	13.203	0.73591×10^{-2}	0.19268	0.23193×10^{-1}	$0.16390 \times 10^{+2}$	$0.22271 \times 10^{+4}$	76.4 ± 0.9
1000	0.733	21.780	0.13368×10^{-1}	0.32301	0.26662×10^{-1}	$0.18054 \times 10^{+2}$	$0.13505 \times 10^{+4}$	75.9 ± 0.9
1040	0.793	35.742	0.26568×10^{-1}	0.36001	0.35709×10^{-1}	$0.21918 \times 10^{+2}$	$0.82498 \times 10^{+3}$	75.7 ± 1.1
1080	0.924	38.495	0.30250×10^{-1}	0.69687	0.41412×10^{-1}	$0.23113 \times 10^{+2}$	$0.76406 \times 10^{+3}$	76.4 ± 0.8
1120	0.962	56.185	0.75100×10^{-1}	$0.12148 \times 10^{+1}$	0.67366×10^{-1}	$0.39364 \times 10^{+2}$	$0.52415 \times 10^{+3}$	92.4 ± 1.1
1160	0.991	46.956	0.96018×10^{-1}	$0.19118 \times 10^{+1}$	0.10810	$0.60147 \times 10^{+2}$	$0.62641 \times 10^{+3}$	167.4 ± 1.8
1200	1.000	62.319	0.33409	$0.13615 \times 10^{+1}$	0.18036	$0.15828 \times 10^{+3}$	$0.47377 \times 10^{+3}$	301.3 ± 4.0
XC3-3 Whole Rock ^q								
400	0.014	33.747	0.15724×10^{-1}	0.46700	0.36409×10^{-1}	$0.13693 \times 10^{+2}$	$0.87083 \times 10^{+3}$	49.1 ± 3.9
500	0.070	39.424	0.19074×10^{-1}	0.44829	0.45769×10^{-1}	$0.14240 \times 10^{+2}$	$0.74656 \times 10^{+3}$	46.7 ± 2.9
600	0.131	34.829	0.17521×10^{-1}	0.34809	0.37043×10^{-1}	$0.14819 \times 10^{+2}$	$0.84576 \times 10^{+3}$	52.2 ± 1.6
660	0.181	28.764	0.14160×10^{-1}	0.35980	0.29730×10^{-1}	$0.14482 \times 10^{+2}$	$0.10227 \times 10^{+4}$	55.7 ± 1.1
720	0.230	24.205	0.11740×10^{-1}	0.24265	0.23245×10^{-1}	$0.14285 \times 10^{+2}$	$0.12168 \times 10^{+4}$	58.4 ± 1.5
780	0.313	20.663	0.92537×10^{-2}	0.18140	0.20582×10^{-1}	$0.13196 \times 10^{+2}$	$0.14260 \times 10^{+4}$	56.5 ± 0.8
840	0.452	11.730	0.47951×10^{-2}	0.15402	0.18118×10^{-1}	$0.12009 \times 10^{+2}$	$0.25044 \times 10^{+4}$	57.2 ± 0.6
950	0.631	17.751	0.77409×10^{-2}	0.29326	0.22829×10^{-1}	$0.12791 \times 10^{+2}$	$0.16523 \times 10^{+4}$	56.8 ± 0.6
1000	0.755	37.904	0.21585×10^{-1}	0.48525	0.32254×10^{-1}	$0.16760 \times 10^{+2}$	$0.77646 \times 10^{+3}$	56.2 ± 0.7
1040	0.837	33.614	0.25590×10^{-1}	0.77329	0.44396×10^{-1}	$0.22352 \times 10^{+2}$	$0.87345 \times 10^{+3}$	79.7 ± 1.0
1080	0.923	47.376	0.48924×10^{-1}	0.97776	0.57074×10^{-1}	$0.30389 \times 10^{+2}$	$0.62115 \times 10^{+3}$	85.8 ± 1.0
1120	0.951	58.879	0.10791	$0.10066 \times 10^{+1}$	0.75255×10^{-1}	$0.54056 \times 10^{+2}$	$0.50094 \times 10^{+3}$	118.2 ± 1.9
1160	0.991	56.008	0.11092	$0.10620 \times 10^{+1}$	0.77654×10^{-1}	$0.58410 \times 10^{+2}$	$0.52657 \times 10^{+3}$	135.9 ± 1.8
1200	1.000	76.718	0.50216	0.86391	0.16955	$0.19337 \times 10^{+3}$	$0.38507 \times 10^{+3}$	231.9 ± 3.8
XC4-3 Whole Rock ^r								
400	0.034	37.502	0.27954×10^{-1}	0.37748	0.31675×10^{-1}	$0.21980 \times 10^{+2}$	$0.78627 \times 10^{+3}$	73.9 ± 2.1
500	0.081	15.615	0.99331×10^{-2}	0.35176	0.19218×10^{-1}	$0.18657 \times 10^{+2}$	$0.18782 \times 10^{+4}$	84.4 ± 1.4
600	0.136	15.030	0.80735×10^{-2}	0.35978	0.20720×10^{-1}	$0.15721 \times 10^{+2}$	$0.19472 \times 10^{+4}$	71.8 ± 1.0
660	0.198	13.136	0.70902×10^{-2}	0.28979	0.18274×10^{-1}	$0.15812 \times 10^{+2}$	$0.22301 \times 10^{+4}$	73.8 ± 0.9
720	0.284	10.843	0.62956×10^{-2}	0.21075	0.15957×10^{-1}	$0.17039 \times 10^{+2}$	$0.27064 \times 10^{+4}$	81.5 ± 1.0

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(continued)

T (°C)	cum. $^{39}\text{Ar}_K$	Atmos. (%)	$^{36}\text{Ar}/^{39}\text{Ar}$	$^{37}\text{Ar}/^{39}\text{Ar}$	$^{38}\text{Ar}/^{39}\text{Ar}$	$^{40}\text{Ar}/^{39}\text{Ar}$	$^{40}\text{Ar}/^{36}\text{Ar}$	Date (Ma)
780	0.390	7.070	0.42561×10^{-2}	0.19120	0.17528×10^{-1}	$0.17613 \times 10^{+2}$	$0.41384 \times 10^{+4}$	87.6 ± 1.0
840	0.507	6.628	0.41112×10^{-2}	0.22265	0.18746×10^{-1}	$0.18106 \times 10^{+2}$	$0.44040 \times 10^{+4}$	90.4 ± 1.1
900	0.619	14.632	0.90336×10^{-2}	0.30563	0.21545×10^{-1}	$0.18116 \times 10^{+2}$	$0.20054 \times 10^{+4}$	82.9 ± 0.9
950	0.730	20.661	0.12922×10^{-1}	0.37251	0.24231×10^{-1}	$0.18374 \times 10^{+2}$	$0.14219 \times 10^{+4}$	78.3 ± 0.9
1000	0.788	23.149	0.18864×10^{-1}	0.67305	0.31985×10^{-1}	$0.23890 \times 10^{+2}$	$0.12664 \times 10^{+4}$	98.1 ± 1.2
1040	0.849	34.634	0.27894×10^{-1}	0.55637	0.34732×10^{-1}	$0.23707 \times 10^{+2}$	$0.84990 \times 10^{+3}$	83.1 ± 0.9
1080	0.944	32.770	0.31649×10^{-1}	$0.10305 \times 10^{+1}$	0.42132×10^{-1}	$0.28331 \times 10^{+2}$	$0.89516 \times 10^{+3}$	101.7 ± 1.2
1120	0.973	40.339	0.74268×10^{-1}	$0.17124 \times 10^{+1}$	0.66378×10^{-1}	$0.54113 \times 10^{+2}$	$0.72862 \times 10^{+3}$	169.3 ± 2.3
1160	0.978	83.437	0.66212	0.88287	0.22903	$0.23445 \times 10^{+3}$	$0.35408 \times 10^{+3}$	201.7 ± 5.3
1200	1.000	64.634	0.20988	$0.26428 \times 10^{+1}$	0.93410×10^{-1}	$0.95674 \times 10^{+2}$	$0.45586 \times 10^{+3}$	177.2 ± 2.8
XC7-2 Whole Rock ^s								
400	0.029	27.008	0.97354×10^{-2}	0.11409	0.21407×10^{-1}	$0.10649 \times 10^{+2}$	$0.10938 \times 10^{+4}$	42.1 ± 1.1
500	0.098	14.732	0.80235×10^{-2}	0.91300×10^{-1}	0.21681×10^{-1}	$0.16076 \times 10^{+2}$	$0.20036 \times 10^{+4}$	73.7 ± 1.5
600	0.145	14.971	0.89609×10^{-2}	0.11871	0.22490×10^{-1}	$0.17656 \times 10^{+2}$	$0.19704 \times 10^{+4}$	80.5 ± 1.3
660	0.179	11.910	0.79473×10^{-2}	0.98730×10^{-1}	0.19679×10^{-1}	$0.19684 \times 10^{+2}$	$0.24768 \times 10^{+4}$	92.7 ± 1.2
720	0.216	17.130	0.12394×10^{-1}	0.61572×10^{-1}	0.17941×10^{-1}	$0.21382 \times 10^{+2}$	$0.17252 \times 10^{+4}$	94.7 ± 1.1
780	0.297	18.493	0.13881×10^{-1}	0.46707×10^{-1}	0.17161×10^{-1}	$0.22191 \times 10^{+2}$	$0.15986 \times 10^{+4}$	96.6 ± 1.1
840	0.425	15.828	0.11428×10^{-1}	0.54177×10^{-1}	0.17746×10^{-1}	$0.21337 \times 10^{+2}$	$0.18672 \times 10^{+4}$	95.9 ± 1.0
900	0.588	9.202	0.61779×10^{-2}	0.73776×10^{-1}	0.19124×10^{-1}	$0.19807 \times 10^{+2}$	$0.32062 \times 10^{+4}$	96.1 ± 1.0
950	0.776	8.230	0.53751×10^{-2}	0.90804×10^{-1}	0.20532×10^{-1}	$0.19244 \times 10^{+2}$	$0.35802 \times 10^{+4}$	94.4 ± 1.0
1000	0.885	12.776	0.87581×10^{-2}	0.14596	0.25888×10^{-1}	$0.20200 \times 10^{+2}$	$0.23064 \times 10^{+4}$	94.2 ± 1.0
1040	0.929	27.240	0.22148×10^{-1}	0.19837	0.39832×10^{-1}	$0.24001 \times 10^{+2}$	$0.10836 \times 10^{+4}$	93.4 ± 1.1
1080	0.965	32.486	0.32394×10^{-1}	0.54871	0.63327×10^{-1}	$0.29367 \times 10^{+2}$	$0.90657 \times 10^{+3}$	105.7 ± 1.2
1120	0.985	49.049	0.70530×10^{-1}	$0.11819 \times 10^{+1}$	0.89805×10^{-1}	$0.42339 \times 10^{+2}$	$0.60029 \times 10^{+3}$	114.8 ± 1.4
1160	0.996	63.515	0.14842	$0.12365 \times 10^{+1}$	0.12090	$0.68932 \times 10^{+2}$	$0.46445 \times 10^{+3}$	133.2 ± 2.2
1200	1.000	69.677	0.41931	0.99860	0.20657	$0.17775 \times 10^{+3}$	$0.42391 \times 10^{+3}$	274.3 ± 5.4
XC8-6 Whole Rock ^t								
400	0.020	29.825	0.16890×10^{-1}	0.25017	0.22232×10^{-1}	$0.16700 \times 10^{+2}$	$0.98872 \times 10^{+3}$	63.2 ± 1.7
500	0.055	32.175	0.18887×10^{-1}	0.24668	0.25961×10^{-1}	$0.17317 \times 10^{+2}$	$0.91687 \times 10^{+3}$	63.3 ± 1.8
600	0.121	27.728	0.14126×10^{-1}	0.21728	0.38724×10^{-1}	$0.15024 \times 10^{+2}$	$0.10636 \times 10^{+4}$	58.6 ± 3.5
660	0.162	22.981	0.10945×10^{-1}	0.22296	0.35630×10^{-1}	$0.14029 \times 10^{+2}$	$0.12818 \times 10^{+4}$	58.3 ± 1.9
720	0.201	24.071	0.12164×10^{-1}	0.16993	0.29909×10^{-1}	$0.14908 \times 10^{+2}$	$0.12256 \times 10^{+4}$	61.0 ± 1.0
780	0.266	19.684	0.93524×10^{-2}	0.12181	0.21830×10^{-1}	$0.14022 \times 10^{+2}$	$0.14993 \times 10^{+4}$	60.7 ± 0.9
840	0.398	15.048	0.68384×10^{-2}	0.10568	0.19019×10^{-1}	$0.13405 \times 10^{+2}$	$0.19602 \times 10^{+4}$	61.4 ± 0.7
900	0.561	9.677	0.41661×10^{-2}	0.14171	0.18630×10^{-1}	$0.12641 \times 10^{+2}$	$0.30341 \times 10^{+4}$	61.5 ± 0.7
950	0.718	10.715	0.47215×10^{-2}	0.20696	0.21354×10^{-1}	$0.12904 \times 10^{+2}$	$0.27330 \times 10^{+4}$	62.1 ± 0.7
1000	0.819	18.693	0.10584×10^{-1}	0.40150	0.31531×10^{-1}	$0.16597 \times 10^{+2}$	$0.15682 \times 10^{+4}$	72.5 ± 0.8
1040	0.870	35.917	0.29437×10^{-1}	0.81910	0.48619×10^{-1}	$0.24075 \times 10^{+2}$	$0.81786 \times 10^{+3}$	82.8 ± 1.2
1080	0.927	42.130	0.39078×10^{-1}	$0.10580 \times 10^{+1}$	0.56602×10^{-1}	$0.27248 \times 10^{+2}$	$0.69728 \times 10^{+3}$	84.6 ± 0.9
1120	0.956	48.732	0.72931×10^{-1}	$0.12656 \times 10^{+1}$	0.75795×10^{-1}	$0.44057 \times 10^{+2}$	$0.60409 \times 10^{+3}$	120.0 ± 1.4
1160	0.990	49.238	0.84625×10^{-1}	$0.12010 \times 10^{+1}$	0.85323×10^{-1}	$0.50632 \times 10^{+2}$	$0.59831 \times 10^{+3}$	136.0 ± 1.7
1200	1.000	78.118	0.37071	$0.10245 \times 10^{+1}$	0.14360	$0.14016 \times 10^{+3}$	$0.37808 \times 10^{+3}$	161.1 ± 4.2
XC9-2 Whole Rock ^u								
400	0.033	30.854	0.12632×10^{-1}	0.17261	0.35090×10^{-1}	$0.12085 \times 10^{+2}$	$0.95668 \times 10^{+3}$	45.2 ± 1.8
500	0.083	15.895	0.85673×10^{-2}	0.14349	0.33009×10^{-1}	$0.15888 \times 10^{+2}$	$0.18545 \times 10^{+4}$	71.8 ± 2.2
600	0.126	24.491	0.14516×10^{-1}	0.16110	0.38200×10^{-1}	$0.17493 \times 10^{+2}$	$0.12051 \times 10^{+4}$	71.0 ± 2.5
660	0.164	12.842	0.86605×10^{-2}	0.14832	0.20101×10^{-1}	$0.19870 \times 10^{+2}$	$0.22943 \times 10^{+4}$	92.6 ± 1.0
720	0.211	13.365	0.91968×10^{-2}	0.11254	0.17896×10^{-1}	$0.20299 \times 10^{+2}$	$0.22072 \times 10^{+4}$	94.0 ± 1.1
780	0.281	8.899	0.59445×10^{-2}	0.93992×10^{-1}	0.17811×10^{-1}	$0.19687 \times 10^{+2}$	$0.33119 \times 10^{+4}$	95.8 ± 1.0
840	0.384	7.037	0.44548×10^{-2}	0.10165	0.22247×10^{-1}	$0.18626 \times 10^{+2}$	$0.41811 \times 10^{+4}$	92.6 ± 1.4
900	0.519	5.177	0.32026×10^{-2}	0.11487	0.20158×10^{-1}	$0.18143 \times 10^{+2}$	$0.56652 \times 10^{+4}$	92.0 ± 1.0
950	0.689	6.279	0.39684×10^{-2}	0.12388	0.21283×10^{-1}	$0.18557 \times 10^{+2}$	$0.46760 \times 10^{+4}$	93.0 ± 1.0
1000	0.792	15.759	0.11066×10^{-1}	0.18573	0.27107×10^{-1}	$0.20691 \times 10^{+2}$	$0.18697 \times 10^{+4}$	93.2 ± 1.0
1040	0.870	26.506	0.20859×10^{-1}	0.18602	0.31548×10^{-1}	$0.23230 \times 10^{+2}$	$0.11137 \times 10^{+4}$	91.3 ± 1.0
1080	0.958	28.216	0.25963×10^{-1}	0.56409	0.48210×10^{-1}	$0.27069 \times 10^{+2}$	$0.10426 \times 10^{+4}$	103.6 ± 1.1
1120	0.985	41.156	0.61347×10^{-1}	$0.12398 \times 10^{+1}$	0.74260×10^{-1}	$0.43850 \times 10^{+2}$	$0.71477 \times 10^{+3}$	136.5 ± 1.7
1160	0.995	64.598	0.18543	$0.14193 \times 10^{+1}$	0.11876	$0.84689 \times 10^{+2}$	$0.45671 \times 10^{+3}$	157.7 ± 2.1
1200	1.000	78.343	0.49456	$0.11243 \times 10^{+1}$	0.21576	$0.18646 \times 10^{+3}$	$0.37703 \times 10^{+3}$	209.3 ± 2.8

Note: J -values: Weighted mean of three fusions of irradiation standard LP-6 Biotite having a calibrated $^{40}\text{Ar}/^{39}\text{Ar}$ age of 128.4 ± 0.2 Ma, based on Fish Canyon Sanidine (28.02 ± 0.28 Ma) (Baksi et al., 1996; Renne et al., 1998); T °C = temperature with uncertainty of ± 2 °C; The date is obtained by using the following equations: Date = $(1/\lambda)\ln(1 + J(^{40}\text{Ar}^*/^{39}\text{Ar}_k))$, and $^{40}\text{Ar}^*/^{39}\text{Ar}_k = ([^{40}\text{Ar}/^{39}\text{Ar}]_m - 295.5[^{36}\text{Ar}/^{39}\text{Ar}]_m + 295.5[^{36}\text{Ar}/^{39}\text{Ar}]_{\text{Ca}}[^{37}\text{Ar}/^{39}\text{Ar}]_m)/(1 - [^{39}\text{Ar}/^{37}\text{Ar}]_{\text{Ca}}[^{37}\text{Ar}/^{39}\text{Ar}]_m) - [^{40}\text{Ar}/^{39}\text{Ar}]_k$, where $[]_{\text{Ca}}$ and $[]_K$ =isotope ratios of argon extracted from irradiated calcium and potassium salts (values cited in the text) and $[]_m$ is isotope ratio of argon extracted from irradiated unknown; Date (Ma)=the date calculated using the following decay constants: $\lambda_e = 0.581 \times 10^{-10} \text{ yr}^{-1}$; $\lambda_\beta = 4.962 \times 10^{-10} \text{ yr}^{-1}$; $\lambda = 5.543 \times 10^{-10} \text{ yr}^{-1}$; $^{40}\text{K}/\text{K} = 0.01167 \text{ atom } \%$ (Steiger and Jäger, 1977); Cum. ^{39}Ar =cumulative fractions of $^{39}\text{Ar}_K$; The quoted error is one standard deviation, including the error in the J -value but not for the errors in the interference corrections; Integrated Date = the date and error calculated from the sum total gas from all steps; Plateau Date = the data and error calculated from the sum total gas from those steps, the ages of which fall within 2 S.D. of each other.

- ^a J -value = $0.00304509 \pm 0.00003178$; Integrated date = 143.3 ± 1.5 Ma; Plateau date = 139.8 ± 1.5 Ma (600–1050 °C).
^b J -value = $0.00304509 \pm 0.00003178$; Integrated date = 99.2 ± 1.0 Ma; Plateau date = 100.9 ± 1.1 Ma (600–1050 °C).
^c J -value = $0.00304509 \pm 0.00003178$; Integrated date = 96.3 ± 1.0 Ma; Plateau date = 96.7 ± 1.0 Ma (650–1050 °C).
^d J -value = $0.00304509 \pm 0.00003178$; Integrated date = 72.0 ± 0.8 Ma.
^e J -value = $0.00304509 \pm 0.00003178$; Integrated date = 143.1 ± 1.4 Ma; Plateau date = 146.9 ± 1.5 Ma (740–1150 °C).
^f J -value = $0.00304509 \pm 0.00003178$; Integrated date = 43.9 ± 0.5 Ma; Plateau date = 45.7 ± 0.5 Ma (780–1090 °C).
^g J -value = $0.00304509 \pm 0.00003178$; Integrated date = 71.7 ± 0.8 Ma; Plateau date = 70.9 ± 0.8 Ma (720–1040 °C).
^h J -value = $0.00304509 \pm 0.00003178$; Integrated date = 66.4 ± 0.7 Ma.
ⁱ J -value = $0.00304509 \pm 0.00003178$; Integrated date = 52.7 ± 0.7 Ma; Plateau date = 53.1 ± 0.6 Ma (780–1040 °C).
^j J -value = $0.00304509 \pm 0.00003178$; Integrated date = 173.4 ± 1.9 Ma.
^k J -value = $0.00304509 \pm 0.00003178$; Integrated date = 87.7 ± 0.9 Ma.
^l J -value = $0.00304509 \pm 0.00003178$; Integrated date = 199.7 ± 2.3 Ma.
^m J -value = $0.00304509 \pm 0.00003178$; Integrated date = 148.4 ± 3.0 Ma.
ⁿ J -value = $0.00304509 \pm 0.00003178$; Integrated date = 136.4 ± 1.4 Ma.
^o J -value = $0.00304509 \pm 0.00003178$; Integrated date = 147.4 ± 1.6 Ma; Plateau date = 143.3 ± 1.6 Ma (600–1120 °C).
^p J -value = $0.00304509 \pm 0.00003178$; Integrated date = 80.2 ± 0.8 Ma; Plateau date = 76.9 ± 0.8 Ma (720–1080 °C).
^q J -value = $0.00304509 \pm 0.00003178$; Integrated date = 66.9 ± 0.7 Ma; Plateau date = 56.8 ± 0.6 Ma (660–1000 °C).
^r J -value = $0.00304509 \pm 0.00003178$; Integrated date = 90.3 ± 0.9 Ma.
^s J -value = $0.00304509 \pm 0.00003178$; Integrated date = 93.4 ± 1.0 Ma; Plateau date = 95.1 ± 1.0 Ma (660–1040 °C).
^t J -value = $0.00304509 \pm 0.00003178$; Integrated date = 70.1 ± 0.8 Ma; Plateau date = 61.2 ± 0.7 Ma (400–900 °C).
^u J -value = $0.00304509 \pm 0.00003178$; Integrated date = 92.8 ± 1.0 Ma; Plateau date = 92.9 ± 1.0 Ma (660–1040 °C).

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