**Late Pliocene onset of the Cona rift, eastern Himalaya, confirms eastward propagation of extension in Himalayan-Tibetan orogen**

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**Introduction**

This supplementary material file contains three sections to expound on contents discussed in the main text. In section 1, we summarize the proposed models for east-west extension. In section 2, we detail the ages of Tibetan rift initiation, which is a supplement to the spatiotemporal pattern of north-trending rifts. In section 3, we summarize testable predictions derived from the working hypothesis.

Fig. S1 shows the age spectra and inverse isochrons for 40Ar/39Ar thermochronology.

Table S1 lists the predictions of the E-W extension models for the rift spatiotemporal patterns. Table S2 shows the activation time of E-W extension across the Himalayan-Tibetan orogen illustrated in the Fig. 1b. Tables S3 and S4 provide the refined dataset from published studies used to create Figs. 1c-e. Tables S5, S6 and S7 show our thermochronological results. Table S8 shows the calculated horizontal extension component for north-trending rifts.

**1. Models for east-west extension**

**1.1.** **Radial spreading**

The radial spreading model describes the expansion of the circumference of the Himalayan arc from north to south in response to the sequential development of south-directed thrusts in the Himalayas (Seeber and Armbruster, 1984; Molnar and Lyon-Caen, 1989; Seeber and Pêcher, 1998; DeCelles et al., 2001; Murphy and Copeland, 2005; Murphy et al., 2009; Haproff et al., 2018). The fault geometry in the Himalayan thrust belt was revealed by fault plane solutions (Baranowski et al., 1984; Molnar and Lyon-Caen, 1989) and the southward development of the thrust system was constrained by geochronological studies and restoration of balanced cross sections (DeCelles et al., 2001; Long et al., 2011; Bhattacharyya et al., 2015). The model predicts that the initiation of rifts should be nearly coeval across the Himalayan front along the strike. Extension magnitude presents a southward decreasing tendency, and at the same time it keeps constant across the Himalayan front.

**1.2. Oroclinal bending**

The oroclinal bending model interprets E-W extension based on the bending of presumed initially linear Himalayan arc (Klootwijk et al., 1985; Schill et al, 2001; Li and Yin, 2008). Due to the rotational underthrusting of the Indian plate, magnetic vectors rotated clockwise in the western Himalaya and counterclockwise in the eastern Himalaya (Klootwijk et al., 1985; Schill et al., 2001), leading to an oroclinal bending of the Himalayan arc. The symmetric dextral strike-slip faults in the western Himalaya and sinistral strike-slip faults in the eastern Himalaya support that oroclinal bending controls active deformation of the Himalayan arc (Ratschbacher et al., 1994; Li and Yin, 2008). The model predicts older initiation ages on two ends of the Himalayan arc and progressively younger ages toward the center rift. Extension magnitude should decrease northward from the southern edge to a zero point where it becomes contraction in Tibet.

**1.3. Lateral slab detachment**

The subducted Indian lithospheric slab detached at both the western and eastern Himalayan syntaxes and propagated bidirectionally to east-central Himalaya. It results in the radial expansion of the asymmetric curvature of the Himalayan arc and related E-W extension (Webb et al., 2017). The model fits with several geophysical and geological observations. For example, tomography has revealed such a slab detachment, which would have initiated in the both syntaxes at ~25 Ma and migrated to east-central Himalaya by ~15 Ma (Replumaz et al., 2010; 2014; Leary et al., 2016), and correspondingly, the magmatic activity in the Himalayas shows a younging trend from the both syntaxes to east-central Himalaya (Guo et al., 2015; Webb et al., 2017). The model predicts that both the onset time and extension magnitude should decrease from the western and eastern Himalayan syntaxes to east-central Himalaya.

**1.4. Convective thinning of lithospheric mantle model**

Convective thinning of the lithospheric mantle can rapidly raise both the gravitational potential energy of the lithosphere (5-10×1012 N m-1) and the surface elevation (>2 km), which were sufficient for the replacement of N-S compression by E-W extension (England and Houseman, 1988; 1989; Molnar et al, 1993; Buer et al, 2015).The model predicts both recent magma upwelling and sudden uplift of the Tibetan Plateau, which have been supported by ~13 Ma basaltic volcanism, xenoliths, geophysical data (Turner et al., 1993; Nelson et al., 1996; Mechie et al., 2004; Buer et al., 2015; Zhu et al., 2017) and the unified changes in both folding and thrusting structure of Indian plate (Kroop, 1991; Molnar et al., 1993) and strengthening of southern Asian monsoon (Cochran., 1990; Molnar et al., 1993) at ~8 Ma, respectively. The sudden and orogen-wide change implies widespread normal faulting should initiate relatively synchronously.

**1.5. Change in the boundary condition model**

Regional boundary condition along the eastern Asian margin changed from a fixed status to a stress-free condition in the Miocene, which perhaps related to the kinematically linked rifts across Tibet and East Asia (Yin, 2000; 2010). The rifts in Tibet and East Asia have broadly similar involvement of lithospheric mantle, initiation ages, and overall volcanic histories (Yin, 2000; 2010). Although the boundary condition of the eastern Asian plate has indeed changed with a period of relatively slow convergence rate in the Miocene (Northrup et al., 1995; Ren et al., 2002; Royden et al., 2008), it is still controversial whether the rifting in the orogen can be produced by such far-field extensional force (Liu and Yang, 2003; Liu et al., 2004). The model predicts that E-W extension across the Himalayan-Tibetan orogen should be synchronous.

**1.6. Oblique convergence**

The oblique convergence model attributes the driving forces to the arc-parallel component of basal shear caused by the northward oblique subduction of the Indian plate (McCaffrey and Nabelek, 1998; Liu and Yang, 2003; McCallister et al., 2014; Styron et al., 2011; 2015). This model has been represented by physical analog experiments (McCaffrey and Nabelek, 1998) and is consistent with the observation that the velocity vectors of India-Asia convergence is approximately parallel along strike and that the strike of the Himalayan orogen is progressively changing (Bendick and Bilham, 2001; Styron et al., 2011). The model predicts that the initiation time should young northward and extension magnitude should decrease from the western and eastern Himalayan syntaxes to the central rifts in eastern Nepal.

**1.7. Gravitational collapse model**

The gravitational collapse model is the earliest model interpreting E-W extension, which means the topographic collapse of the Tibetan Plateau after reaching the maximum (Molnar and Tapponnier, 1978; Dewey, 1988; Harrison et al., 1992; Coleman and Hodges, 1995; Searle, 1995; Blisniuk et al., 2001). This interpretation is mainly based on the observations that rifts locate at high elevations (Molnar and Tapponnier, 1978; Mercier et al, 1987; Dewey, 1988) and have simultaneous onset time (Harrison et al., 1992; Coleman and Hodges, 1995; Blisniuk et al., 2001). Recently, gravitational collapse has been widely accepted to cause the eastward lithospheric flow (Yin and Taylor, 2011; Bischoff and Flesch, 2018). As the Indian indenter moves toward the Tarim block, higher strain rates developed in the western part of Himalayan-Tibetan orogen because of western narrower deformation zone, leading to a more rapid uplift there (Liu and Yang, 2003; Yang and Liu, 2013). Potentially earlier collision in the west due to the shape of Greater India (Meng et al., 2020) may have enhanced this effect. The west-to-east changing gravitational potential energy (GPE) drove the eastward lithospheric flow, and in turn generated observed normal faulting (Taylor et al., 2003; Yin and Taylor, 2011; Bischoff and Flesch, 2018; 2019; Pang et al., 2018). Therefore, eastward lithospheric flow driven by gravitational collapse model predicts a monotonic decreasing trend in the initiation time and horizontal extension magnitude of rifting towards the east when GPE developed asynchronously and was greater in the west than the east.

**1.8. Slab tearing model**

Vertical tearing of the Indian lithospheric slab along the north-south direction has recently been demonstrated to be associated with the rifting by various evidence (Yin, 2000; Xiao et al., 2007; Chen et al., 2015; Liang et al., 2016; Li and Song, 2018). It is mainly based on the signiﬁcant lateral variations of the underthrusting Indian lithospheric slab (Li et al., 2008; Nábělek et al., 2009; Kind and Yuan, 2010; Chen et al., 2015; Peng et al., 2016; Pei et al., 2016), and upper-mantle low-velocity anomalies, which are spatially correlated with the Tangra Yum Co, Yadong-Gulu and Cona rifts (Liang et al., 2016).

**2. Initiation of E-W extension**

The north-trending rifts are widely developed in the Himalayan-Tibetan system. In the main text, the initiation age of rifting in the Himalayas was described. Here, we describe the ages of Tibetan rift initiation.

**2.1. Qiangtang terrane**

In the Qiangtang terrane, only the Shuang Hu rift (a in Fig. 1b) has been robustly investigated to constrain the onset of E-W extension with diverse ages varying from 13.5 Ma to 4 Ma. The former was based on 40Ar/39Ar and Rb/Sr thermochronological data on mineralization in the main graben-bounding normal fault zone (Blisniuk et al., 2001), and the latter was inferred from the total amount of normal slip and slip rate (Yin et al., 1999). The scarce and highly variable age estimates do not allow a substantive constraint on the initiation of faulting, and therefore this rift is not included in the compilation of spatiotemporal pattern.

**2.2. Lhasa terrane**

In the North Lunggar rift (b in Fig. 1b), zircon U-Pb ages of deformed mylonitic leucogranite (Kapp et al., 2008) along the ductile detachment suggested that E-W extension initiated at ~15 Ma. Thermal modeling (Sundell et al., 2013) and apatite and zircon (U-Th)/He ages of growth strata in the Lunggar basin showed the initiation of rifting at 10-8 Ma (Woodruff et al., 2013). In the southern continuation of the Lunggar rift (c in Fig. 1b), PECUBE modeling based on zircon (U-Th)/He data suggested that normal faulting began at 16-12 Ma (Styron et al., 2013). To the east, in the Lopukangri rift (d in Fig. 1b), biotite 40Ar/39Ar thermochronology of the footwall rocks suggested that E-W extension started at 15-14 Ma (Sanchez et al., 2013). In the Tangra Yum Co rift (e in Fig. 1b), apatite and zircon (U-Th)/He ages from vertical transects in this area revealed two distinct episodes of rifting at ~13 Ma and ~6 Ma, respectively (Dewane et al., 2006). In the Xianza rift (f in Fig. 1b), zircon and apatite (U-Th)/He ages constrained E-W extension at 14 Ma followed by an accelerated exhumation of 10-6 Ma of the rift flanks (Hager et al., 2009). Farther to the east, mica and K-feldspar 40Ar/39Ar date from the footwall of Nyainqentanghla ductile shear zone (h in Fig. 1b) recorded a rapid cooling event at ~8 Ma, indicating the onset of extension (Harrison et al., 1995; Kapp et al., 2005). In the northeastern part of this rift system (g in Fig. 1b), apatite (U-Th)/He data indicated onset of rifting at ~7-5 Ma in the Gulu rift (Stockli et al., 2002).

**3. Testable Predictions from the working hypothesis**

(1) Breakoff of the Neo-Tethyan oceanic slab occurred at ~50-40 Ma, which induced the asthenospheric upwelling heating of overlying Lhasa crust. This may be responsible for the early phase of adakitic rocks (~35-24 Ma).

(2) The detachment of Indian continental slab began at ~25 Ma in the west and migrated to the eastern end at ~8 Ma, which corresponds in time and trend with the post-collision magmatic rocks in the Lhasa terrane. Slab detachment may explain the eastward progressive emplacement of the later phase of adakitic rocks (~20-10 Ma) and the ultrapotassic rocks distributed along the east-west belt (~25-8 Ma).

(3) Slab tearing that initiated at ~17 Ma caused the clockwise toroidal mantle flow around the broken slab edge and progressive southward production of ultrapotassic rocks along the north-trending rifts.

(4) Final breakoff of the Indian continental slab that finished at ~10-8 Ma may explain the termination of post-collision magmatism in the Lhasa terrane.

(5) Slab detachment and tearing processes generated a rollback effect for the eastern segment of the slab, which can explain the southward migration of ultrapotassic rocks in the eastern Lhasa terrane relative to the western.

(6) Eastward-propagating lateral slab detachment resulted in an associated dynamic topographic rise that built greater GPE in the western Himalaya than the east. It further gave rise to eastward lithospheric flow, inducing the development of north-trending rifts and associated v-shaped conjugate strike-slip faults along the BNS. This west-to-east progression was enhanced by clockwise toroidal mantle flow around the longitudinally tearing slab.



Fig. S1. Age spectra (left) and inverse isochrons (right) for 40Ar/39Ar thermochronology.

**Table S1.** Predictions of the models explaining E-W extension

|  |  |  |  |
| --- | --- | --- | --- |
| Model | Extent of E-W extension | Temporal patternof rifts | Extension magnitudepattern |
| Radial spreading | Himalayas | Youngs southward and keeps synchronous along the strike of the Himalayan arc | Increasing northward and keeping constant across the Himalayas |
| Oroclinal bending | Himalayas | Youngs toward the center from the westernmost and the easternmost rifts  | Decreasing northward from the Himalayas  |
| Lateral slab detachment | Himalayas | Youngs toward the east-central Himalaya from the both ends | Decreasing toward the east-central Himalaya from the both ends |
| Convective thinning  | Himalayan-Tibetan orogen | Synchronous onset time |  |
| Change in the boundary condition | Himalayan-Tibetan orogen and East Asia | Synchronous onset time |  |
| Oblique convergence | Himalayas and southern and central Tibet system | Youngs northward and toward the center | Increasing eastward and westward from eastern Nepal |
| Gravitational collapse-driven eastward lithospheric flow  | Himalayan-Tibetan orogen | Youngs eastward  | Decreasing eastward |
| Slab tearing | Himalayan-Tibetan orogen | Special temporal sequence |  |

**Table S2.** Summary of the activation time of E-W extension across the Himalayan-Tibetan orogen

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
| Number in Fig. 1b | Name | Initiation Age (Ma) | Basis | Rheology | References |
| (a) | Shuang Hu  | >13.5 | Rb-Sr and 40Ar/39Ar age of mineralization in the main graben-bounding normal fault zone | Brittle | Blisniuk et al., 2001 |
|  |  | <4 | Amount of normal slip of ~7 km and minimum slip rate of ~2 mm a-1 estimated by fault scarp | Brittle | Yin et al., 1999 |
| (b) | North Lunggar | ~15 | Oldest mean U-Pb ages of zircons in deformed mylonitic leucogranite | Ductile | Kapp et al., 2008 |
|  |  | >10 | Apatite and zircon (U-Th)/He thermochronology and thermal modeling | Brittle-ductile | Sundell et al., 2013 |
|  |  | 10-8 | Apatite and zircon (U-Th)/He ages from Neogene growth strata suggesting rapid exhumation | Brittle | Woodruff et al., 2013 |
| (c) | South Lunggar | 16-12 | Thermokinematic modeling of zircon (U-Th)/He data | Ductile | Styron et al., 2013 |
| (d) | Lopukangri | 15-14 | Footwall and hanging wall 40Ar/39Ar mica ages | Brittle | Sanchez et al., 2013 |
| (e) | Tangra Yum Co  | 13 | Footwall and hanging wall apatite and zircon (U-Th)/He ages | Brittle | Dewane et al., 2006 |
| (f) | Xainza | 14 | Footwall apatite and zircon (U-Th)/He ages | Brittle | Hager et al., 2009 |
| (g) | Gulu | 7-5 | Apatite (U-Th)/He ages from the western flank of rift | Brittle | Stockli et al., 2002 |
| (h) | Nyainqentanghla | 8 | Footwall and mylonitic shear zone 40Ar/39Ar mica and K-feldspar ages | Ductile | Harrison et al., 1995 |
|  |  | 8 | Footwall 40Ar/39Ar K-feldspar ages | Brittle | Kapp et al., 2005 |
| (i) | Leo Pargil | 23 | Monazite U-Pb ages of leucogranite combined with contemporaneous onset of decompression and shearing  | Brittle | Langille et al., 2012 |
|  |  | 16-14 | Footwall 40Ar/39Ar muscovite ages | Ductile | Thiede et al., 2006 |
|  |  | 16 | Footwall 40Ar/39Ar syn-kinematic muscovite ages | Ductile | Hintersberger et al., 2010 |
| (j) | Gurla Mandhata | ~15 | Mean Pb-Th ages of monazite in undeformed and deformed leucogranite bodies | Ductile | Murphy and Copeland, 2005 |
|  |  | 14-11 | Thermokinematic modeling of zircon (U-Th)/He data | Ductile | McCallister et al., 2014 |
|  |  | 9 | Footwall 40Ar/39Ar muscovite and biotite ages | Ductile | Murphy et al., 2002 |
|  |  | ~9 | Vertebrate fossils and magnetostratigraphy constrains of lowest sedimentary basin fill | Brittle | Saylor et al., 2009; 2010 |
| (k) | Thakkhola | >14 | Muscovite 40Ar/39Ar ages from N-S trending hydrothermal vein | Tension vein | Coleman and Hodges, 1995 |
|  |  | ~11-10 | Magnetostratigraphy of the oldest basin fill with growth faults | Ductile | Garzione et al., 2000; 2003 |
|  |  | ~17 | Muscovite 40Ar/39Ar geochronology and microstructural information | Ductile | Larson et al., 2019 |

Continued **Table S2**

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
| Number inFig. 1b | Name | Initiation Age (Ma) | Basis | Rheology | References |
| (l) | Kung Co | 13-12 | Thermal modeling of zircon and apatite (U-Th)/He data | Brittle | Lee et al., 2011 |
|  |  | <4 | Extrapolation of apatite (U-Th)/He age indicating rapid exhumation rate | Brittle | Mahéo et al., 2007 |
| (m) | Dinggye | ~13-10 | Footwall muscovite and biotite 40Ar/39Ar ages in the deformed leucogranites and mylonized gneiss | Ductile | Zhang and Guo, 2007 |
|  |  | ~12-10 | Footwall 40Ar/39Ar biotite ages in the paragneisses | Ductile | Kali et al., 2010 |
| (n) | Yadong  | <10 | Monazite Th-Pb ages in the pluton related with STD cut by the Yadong rift | Ductile | Edwards and Harrison, 1997 |
|  |  | <11.5 | Xenotime and monazite U-Pb in the granite cut by the Yadong rift | Ductile | Ratschbacher et al., 2011 |
|  |  | 12.3 | Muscovite 40Ar/39Ar ages from mylonitic gneiss in the Yadong shear zone, | Ductile | Xu et al., 2013 |

**Table S3.** Summary of ages and locations of adakitic rocks in the Lhasa terrane. The dataset excludes 40Ar/39Ar ages with obvious extra or loss of 40Ar.

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
| Location | Latitude | Longitude | Age(Ma) | Method | References |
| Pangong | 34.1 | 78.1 | 16.6 | Zircon U-Pb | Ravikant et al., 2009 |
| Pangong | 34.1 | 78.1 | 18.2 | Zircon U-Pb | Ravikant et al., 2009 |
| Pangong | 34.1 | 78.1 | 19.1 | Zircon U-Pb | Ravikant et al., 2009 |
| Bangba | 31 | 81 | 17.01 | Zircon U-Pb | Chen et al., 2011 |
| Kailas | 31.25 | 81 | 24.6 | Zircon U-Pb | Decelles et al., 2011 |
| Kailas | 31.25 | 81 | 24.17 | Zircon U-Pb | Decelles et al., 2011 |
| Yare | 31.3 | 82.1 | 16.8 | Zircon U-Pb | Hou et al., 2013 |
| Mayum | 30.5 | 82.4 | 18.4 | Zircon U-Pb | Hu et al., 2006; Jiang et al., 2009 |
| Mayum | 30.6 | 82.5 | 17.68 | Biotite Ar/Ar | Jiang et al., 2006 |
| Daggyai Tso | 30 | 85.6 | 18.8 | Phlogopite Ar/Ar | Williams et al., 2004 |
| Zhuno | 29.7 | 87.5 | 15.6 | Zircon U-Pb | Zheng et al., 2007; Gao et al., 2010 |
| Xigaze | 29.3 | 88 | 15.4 | Sanidine Ar/Ar | Yin et al., 1994 |
| Xigaze | 29.3 | 88 | 18.3 | Hornblende Ar/Ar | Yin et al., 1994 |
| Nanmuqie | 29.8 | 88.3 | 14.3 | Zircon U-Pb | Xu et al., 2010 |
| Nanmuqie | 29.8 | 88.3 | 14.4 | Zircon U-Pb | Xu et al., 2010 |
| Kuday | 29 | 88.4 | 11.49 | Zircon U-Pb | King et al., 2007 |
| Kuday | 29 | 88.4 | 11.16 | Biotite Ar/Ar | King et al., 2007 |
| Kuday | 29 | 88.4 | 9.13 | Biotite Ar/Ar | King et al., 2007 |
| Kuday | 29 | 88.4 | 10.51 | Biotite Ar/Ar | King et al., 2007 |
| Xigaze | 29.4 | 88.8 | 15 | Whole rock Ar/Ar | Chung et al., 2003 |
| Xigaze | 29.3 | 88.9 | 18.4 | Whole rock Ar/Ar | Chung et al., 2003 |
| Chongjiang | 29.6 | 89.6 | 14.5 | Zircon U-Pb | Hou et al., 2004 |
| Chongjiang | 29.6 | 89.6 | 15.6 | Zircon U-Pb | Hou et al., 2004 |
| Chongjiang | 29.6 | 89.6 | 14.6 | Zircon U-Pb | Xu et al., 2010 |
| Dazhuqu | 29.3 | 89.6 | 19.5 | Plagioclase Ar/Ar | Aitchison et al., 2009 |
| Dazhuqu | 29.3 | 89.6 | 19.7 | Plagioclase Ar/Ar | Aitchison et al., 2009 |
| Dazhuqu | 29.3 | 89.6 | 22.2 | Biotite Ar/Ar | Aitchison et al., 2009 |
| Bairong | 29.5 | 89.9 | 14.2 | Zircon U-Pb | Li et al., 2011 |
| Bairong | 29.5 | 89.9 | 14.8 | Zircon U-Pb | Li et al., 2011 |
| Tinggong | 29.5 | 89.9 | 14.2 | Zircon U-Pb | Xu et al., 2010 |
| Tinggong | 29.5 | 89.9 | 16 | Zircon U-Pb | Li et al., 2011 |
| Pagu | 29.5 | 90 | 14.3 | Zircon U-Pb | Xu et al., 2010 |
| Pagu | 29.5 | 90 | 14 | Zircon U-Pb | Xu et al., 2010 |
| Chongjiang | 29.6 | 90 | 15.3 | Zircon U-Pb | Ji et al., 2009 |
| Chongjiang | 29.6 | 90 | 13.7 | Zircon U-Pb | Ji et al., 2009 |
| Chongjiang | 29.6 | 90 | 13.5 | Zircon U-Pb | Ji et al., 2009 |
| Majiang | 29.5 | 90 | 15.1 | Zircon U-Pb | Chung et al., 2009 |
| Nymo | 29.5 | 90 | 14.9 | Zircon U-Pb | Ji et al., 2009 |
| Chongjiang | 29.6 | 90 | 12.22 | Plagioclase Ar/Ar | Qu et al., 2003 |
| Chongjiang | 29.6 | 90 | 13.5 | Biotite Ar/Ar | Qu et al., 2003 |
| Baijin | 29.4 | 90.7 | 21.3 | Zircon U-Pb | Ji et al., 2009 |
| Nanmu | 29.5 | 90.8 | 17 | Zircon U-Pb | Ji et al., 2009 |

Continued **Table S3**

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
| Location | Latitude | Longitude | Age(Ma) | Methods | References |
| Nanmu | 29.5 | 90.8 | 15.3 | Zircon U-Pb | Ji et al., 2009 |
| Nemu | 29.5 | 90.8 | 12.75 | Zircon U-Pb | Chen et al., 2011 |
| Nanmu | 29.5 | 90.8 | 17.7 | Zircon U-Pb | Ji et al., 2009 |
| Jiama | 29.5 | 90.9 | 15.5 | Zircon U-Pb | Chen et al., 2011 |
| Jiama | 29.5 | 90.9 | 15.46 | Zircon U-Pb | Chen et al., 2011 |
| Jiama | 29.5 | 90.9 | 16.6 | Whole rock Ar/Ar | Chung et al., 2003 |
| Jiama | 29.5 | 90.9 | 16.4 | Sanidine Ar/Ar | Chung et al., 2003 |
| Qiangdui | 29.5 | 91.2 | 17.1 | Zircon U-Pb | Li et al., 2011 |
| Qiangdui | 29.5 | 91.2 | 19 | Zircon U-Pb | Li et al., 2011 |
| Qiangdui | 29.5 | 91.2 | 19.1 | Zircon U-Pb | Li et al., 2011 |
| Lakang'e | 29.6 | 91.3 | 12.5 | Plagioclase Ar/Ar | Qu et al., 2003 |
| Lakang'e | 29.6 | 91.3 | 13.42 | Biotite Ar/Ar | Qu et al., 2003 |
| Qulong | 29.6 | 91.6 | 17.58 | Zircon U-Pb | Hou et al., 2004 |
| Jiama | 29.6 | 91.6 | 17 | Zircon U-Pb | Chung et al., 2003 |
| Jiama | 26.7 | 91.8 | 15 | Zircon U-Pb | Chung et al., 2003 |
| Jiama | 26.7 | 91.8 | 13.2 | Whole rock Ar/Ar | Chung et al., 2003 |
| Jiama | 26.7 | 91.8 | 15.2 | Sanidine Ar/Ar | Chung et al., 2003 |
| Mingze | 29.3 | 91.8 | 31.7 | Zircon U-Pb | Zheng et al., 2012b |
| Mingze | 29.3 | 91.8 | 30.4 | Zircon U-Pb | Zheng et al., 2012b |
| Yaja/Zedong | 29.3 | 91.9 | 30.3 | Zircon U-Pb | Chung et al., 2009 |
| Yaja/Zedong | 29.3 | 91.9 | 31 | Zircon U-Pb | Chung et al., 2009 |
| Yaja | 29.3 | 91.9 | 30.4 | Zircon U-Pb | Harrison et al., 2000 |
| Sangri | 29.3 | 91.9 | 29.6 | Zircon U-Pb | Zhang et al., 2014 |
| Chongmuda | 29.3 | 91.9 | 30.2 | Zircon U-Pb | Jiang et al., 2014 |
| Chongmuda | 29.3 | 91.9 | 31 | Zircon U-Pb | Jiang et al., 2014 |
| Chongmuda | 29.3 | 91.9 | 30.3 | Zircon U-Pb | Zheng et al., 2012b |
| Chongmuda | 29.3 | 91.9 | 29.8 | Zircon U-Pb | Zheng et al., 2012b |
| Chongmuda | 29.3 | 91.9 | 28.5 | Zircon U-Pb | Zheng et al., 2012b |
| Bayi | 29.7 | 94.3 | 22 | Zircon U-Pb | Zhang et al., 2010 |
| Dangru | 29.6 | 94.4 | 25.7 | Zircon U-Pb | Zhang et al., 2014 |
| Linzhi | 29.6 | 94.5 | 26 | Zircon U-Pb | Booth et al., 2004 |
| Lunan | 29.6 | 94.6 | 25.4 | Zircon U-Pb | Zhang et al., 2010 |
| Linzhi | 29.6 | 94.6 | 26.5 | Zircon U-Pb | Zhang et al., 2014 |
| Linzhi | 29.6 | 94.7 | 26.1 | Zircon U-Pb | Zheng et al., 2012a |
| Linzhi | 29.6 | 94.7 | 27.1 | Zircon U-Pb | Zheng et al., 2012a |
| Linzhi | 29.6 | 94.7 | 26.2 | Zircon U-Pb | Chung et al., 2003 |
| Beibeng | 29.3 | 95.3 | 27.5 | Zircon U-Pb | Pan et al., 2012 |
| Beibeng | 29.3 | 95.3 | 29.9 | Zircon U-Pb | Pan et al., 2012 |
| Lengduo | 29.5 | 95.4 | 28.1 | Zircon U-Pb | Zhang et al., 2014 |
| Damu | 29.5 | 95.4 | 28.5 | Zircon U-Pb | Zhang et al., 2014 |
| Damu | 29.5 | 95.5 | 27.6 | Zircon U-Pb | Pan et al., 2012 |
| Balonggong | 29.6 | 95.5 | 27.1 | Zircon U-Pb | Pan et al., 2012 |
| Balonggong | 29.6 | 95.5 | 26.5 | Zircon U-Pb | Pan et al., 2012 |
| Bomi | 29.8 | 95.7 | 23.7 | Zircon U-Pb | Pan et al., 2012 |

**Table S4.** Summary of ages and locations of ultrapotassic rocks in the Lhasa terrane. Magmatic data based on the compilation by Guo and Wilaon (2019) and other references. The dataset excludes 40Ar/39Ar ages with obvious extra or loss of 40Ar.

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
| Location | Latitude | Longitude | Age(Ma) | Methods | References |
| Shiquanhe | 32.5 | 80.1 | 21.2 | Plagioclase Ar/Ar | Williams et al., 2004 |
| Shiquanhe | 32.5 | 80.1 | 22.6 | Biotite Ar/Ar | Kapp et al., 2003 |
| S Bongba | 32 | 81.2 | 23.3 | Whole rock Ar/Ar | Miller et al., 1999 |
| S Bongba | 32 | 81.2 | 25.4 | Whole rock Ar/Ar | Miller et al., 1999 |
| Manasarowar | 32 | 81.2 | 17 | Plagioclase Ar/Ar | Miller et al., 1999 |
| Manasarowar | 32 | 81.2 | 17 | Biotite Ar/Ar | Miller et al., 1999 |
| Manasarowar | 32 | 81.2 | 16.7 | Biotite Ar/Ar | Miller et al., 1999 |
| Xungba | 32.1 | 81.3 | 23.4 | Zircon U-Pb | Liu et al., 2014b |
| Chajiasi | 32 | 81.3 | 23.97 | Zircon U-Pb | Hu et al., 2012 |
| Kailas | 31 | 81.5 | 16.9 | Plagioclase Ar/Ar | Aitchison et al., 2009 |
| Xungba | 32 | 81.7 | 24.1 | Zircon U-Pb | Liu et al., 2011 |
| Xungba | 32 | 81.7 | 23.3 | Zircon U-Pb | Liu et al., 2011 |
| Xungba | 32 | 81.7 | 22.7 | Zircon U-Pb | Liu et al., 2014a |
| Xungba | 32 | 81.8 | 23.3 | Zircon U-Pb | Liu et al., 2014b |
| S Xungba | 31.75 | 81.8 | 22.9 | Whole rock Ar/Ar | Miller et al., 1999 |
| Xungba | 31.9 | 81.8 | 23 | Phlogopite Ar/Ar | Miller et al., 1999 |
| E Jarga | 32 | 81.8 | 18.5 | Phlogopite Ar/Ar | Miller et al., 1999 |
| E Jarga | 32 | 81.8 | 18.9 | Phlogopite Ar/Ar | Miller et al., 1999 |
| S Xungba | 31.85 | 81.8 | 18.1 | Phlogopite Ar/Ar | Miller et al., 1999 |
| Xungba | 31.85 | 82 | 23.0 | Zircon U-Pb | Liu et al., 2014a |
| Xungba | 31.85 | 82 | 23.8 | Zircon U-Pb | Liu et al., 2014a |
| Xungba | 31.8 | 82.1 | 23.9 | Zircon U-Pb | Liu et al., 2011 |
| Xungba | 32 | 82.3 | 23.5 | Zircon U-Pb | Liu et al., 2014b |
| Sailipu | 31.3 | 82.6 | 17.01 | Zircon U-Pb | Sun et al., 2008 |
| Sailipu | 31.3 | 82.6 | 16.28 | Zircon U-Pb | Sun et al., 2008 |
| Sailipu | 31.3 | 82.6 | 17.67 | Zircon U-Pb | Sun et al., 2008 |
| Sailipu | 31.45 | 82.75 | 17.58 | Phlogopite Ar/Ar | Wang et al., 2008 |
| Sailipu | 31.3 | 83 | 18.1 | Zircon U-Pb | Liu et al., 2014a |
| Zabuye | 31.4 | 84.3 | 15.56 | Whole rock Ar/Ar | Chen et al., 2006 |
| Zabuye | 31.4 | 84.3 | 16.16 | Sanidine Ar/Ar | Nomade et al., 2004 |
| Zabuye | 31.4 | 84.3 | 16.12 | Sanidine Ar/Ar | Nomade et al., 2004 |
| Zabuye | 31.4 | 84.3 | 16.02 | Sanidine Ar/Ar | Nomade et al., 2004 |
| Zabuye | 31.4 | 84.3 | 16.1 | Biotite Ar/Ar | Nomade et al., 2004 |
| Zabuye | 31.4 | 84.3 | 16.01 | Sanidine Ar/Ar | Nomade et al., 2004 |
| Zabuye | 31.4 | 84.3 | 16.11 | Biotite Ar/Ar | Nomade et al., 2004 |
| Zabuye | 31.4 | 84.4 | 15.7 | Zircon U-Pb | Liu et al., 2014a |
| Zabuye | 31.4 | 84.4 | 16 | Zircon U-Pb | Liu et al., 2014a |
| Maiga | 30.82 | 84.44 | 17.4 | Biotite Ar/Ar | Ding et al., 2006 |
| Konglongxiang | 30.5 | 86.1 | 21.38 | Whole rock Ar/Ar | Chen et al., 2010 |
| Dangreyongcuo | 30.9 | 86.4 | 13.4 | Biotite Ar/Ar | Zhao et al., 2006 |
| Chazi | 30.13 | 86.43 | 11.7 | Zircon U-Pb | Guo et al., 2013 |

Continued **Table S4**

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
| Location | Latitude | Longitude | Age(Ma) | Methods | References |
| Xuru lake | 30.07 | 86.5 | 11.5 | Biotite Ar/Ar | Zhao et al., 2006 |
| Chazi | 30.1 | 86.5 | 13.1 | Sanidine Ar/Ar | Ding et al., 2003 |
| Chazi | 30 | 86.5 | 8.2 | Sanidine Ar/Ar | Ding et al., 2003 |
| Pabbai Zong | 30 | 86.5 | 13.3 | Phlogopite Ar/Ar | Williams et al., 2001 |
| Pabbai Zong | 30 | 86.5 | 13.8 | Biotite Ar/Ar | Williams et al., 2001 |
| Wenbu | 31.08 | 86.53 | 22.5 | Sanidine Ar/Ar | Ding et al., 2003 |
| Wenbu | 31 | 86.6 | 22.9 | Sanidine Ar/Ar | Ding et al., 2003 |
| Yiqian | 30.75 | 86.72 | 12.9 | Zircon U-Pb | Liu et al., 2014a |
| Yiqian | 30.75 | 86.72 | 11.2 | Zircon U-Pb | Liu et al., 2014a |
| Yiqian | 30.75 | 86.72 | 13.5 | Biotite Ar/Ar | Ding et al., 2006 |
| Mibale | 30.85 | 86.67 | 19.04 | Whole rock K/Ar | Xie et al., 2004 |
| Mibale | 30.85 | 86.67 | 12.6 | Whole rock K/Ar | Xie et al., 2004 |
| Mibale | 30.85 | 86.67 | 14.22 | Whole rock K/Ar | Xie et al., 2004 |
| Chazi | 30.1 | 86.8 | 13.3 | Phlogopite Ar/Ar | Ding et al., 2003 |
| Wuyu Namulin | 29.4 | 89 | 13.1 | Plagioclase Ar/Ar | Zhou, 2002 |
| Wuyu Namulin | 29.4 | 89 | 13.63 | Plagioclase Ar/Ar | Zhou, 2002 |
| Wuyu Namulin | 29.4 | 89 | 12 | Plagioclase Ar/Ar | Zhou, 2002 |
| Namulin | 29.4 | 89.5 | 13.9 | Biotite Ar/Ar | Williams et al., 2004 |
| Namulin | 29.4 | 89.5 | 12.5 | Biotite Ar/Ar | Williams et al., 2004 |
| Namulin | 29.7 | 89.6 | 14.03 | Sanidine Ar/Ar | Spicer et al., 2003 |
| Namulin | 29.7 | 89.6 | 15.25 | Sanidine Ar/Ar | Spicer et al., 2003 |
| Namulin | 29.7 | 89.6 | 15.03 | Sanidine Ar/Ar | Spicer et al., 2003 |
| Namulin | 29.7 | 89.6 | 15.1 | Sanidine Ar/Ar | Spicer et al., 2003 |
| Namulin | 29.7 | 89.6 | 12.96 | Biotite Ar/Ar | Zhou et al., 2010 |
| Namulin | 29.7 | 89.6 | 12.57 | Plagioclase Ar/Ar | Zhou et al., 2010 |
| Namulin | 29.7 | 89.6 | 15.48 | Plagioclase Ar/Ar | Zhou et al., 2010 |
| Namulin | 29.7 | 89.6 | 11.09 | K-feldspar Ar/Ar | Zhou et al., 2010 |
| MaQuiang | 29.9 | 89.8 | 12.9 | Plagioclase Ar/Ar | Coulon et al., 1986 |
| MaQuiang | 29.9 | 89.8 | 15.8 | Hornblende Ar/Ar | Coulon et al., 1986 |
| MaQuiang | 29.9 | 89.8 | 10.1 | Biotite Ar/Ar | Coulon et al., 1986 |
| MaQuiang | 29.9 | 89.8 | 12.9 | Biotite Ar/Ar | Coulon et al., 1986 |
| MaQuiang | 29.9 | 89.8 | 14.4 | Biotite Ar/Ar | Coulon et al., 1986 |
| Yangying | 29.7 | 90.4 | 10.6 | Sanidine Ar/Ar | Nomade et al., 2004 |
| Yangying | 29.7 | 90.4 | 10.88 | Biotite Ar/Ar | Nomade et al., 2004 |
| Yangying | 29.7 | 90.4 | 11.14 | Sanidine Ar/Ar | Zhou et al., 2010 |
| Yangying | 29.7 | 90.4 | 10.84 | Sanidine Ar/Ar | Zhou et al., 2010 |
| Yangying | 29.7 | 90.4 | 10.32 | Biotite Ar/Ar | Zhou et al., 2010 |
| Yangying | 29.7 | 90.4 | 10.62 | Zircon U-Pb | Zhang et al., 2017 |
| Yangying | 29.7 | 90.4 | 10.72 | Zircon U-Pb | Zhang et al., 2017 |

**Table S5** Full summary of the 40Ar/39Ar thermochronological data

|  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
| T(°C) | Age | ±Age | %40Ar\* | 39Ar(Moles) | 40/39Ar | ±40/39Ar | 38/39Ar | ±38/39Ar | 37/39Ar | ±37/39Ar | 36/39Ar | ±36/39Ar | 40Ar\*/39Ar | ±40Ar\*/39Ar |
| CN-2-Bt J = 0.004101 |
| 600 | 6.29 | 1.44 | 38.73 | 3.01E-14 | 2.19310  | 0.01312  | 0.06844  | 0.00421  | 5.21017  | 0.07879  | 0.00594  | 0.00066  | 0.85226  | 0.19565  |
| 650 | 7.51 | 0.62 | 63.68 | 2.99E-13 | 1.59607  | 0.01968  | 0.05266  | 0.00031  | 0.50151  | 0.02436  | 0.00207  | 0.00028  | 1.01667  | 0.08418  |
| 700 | 7.42 | 0.97 | 59.22 | 1.38E-13 | 1.69554  | 0.06539  | 0.05374  | 0.00047  | 0.78909  | 0.00517  | 0.00253  | 0.00039  | 1.00462  | 0.13192  |
| 750 | 7.34 | 0.64 | 59.51 | 7.22E-14 | 1.67053  | 0.01044  | 0.05538  | 0.00110  | 0.45813  | 0.01306  | 0.00239  | 0.00029  | 0.99442  | 0.08630  |
| 800 | 6.87 | 0.9 | 32.69 | 3.10E-14 | 2.84511  | 0.06290  | 0.04977  | 0.00576  | 0.62676  | 0.00018  | 0.00663  | 0.00035  | 0.93031  | 0.12224  |
| 850 | 6.70 | 0.61 | 31.71 | 1.53E-14 | 2.86074  | 0.07081  | 0.07138  | 0.00832  | 1.09665  | 0.13698  | 0.00688  | 0.00014  | 0.90789  | 0.08214  |
| 900 | 6.02 | 0.98 | 12.14 | 1.30E-14 | 6.70872  | 0.08428  | 0.05130  | 0.00527  | 0.89834  | 0.02317  | 0.02017  | 0.00035  | 0.81518  | 0.13355  |
| 950 | 6.71 | 0.82 | 20.96 | 2.54E-14 | 4.33517  | 0.04251  | 0.04598  | 0.00044  | 0.18294  | 0.00767  | 0.01162  | 0.00035  | 0.90882  | 0.11069  |
| 1000 | 7.01 | 0.9 | 29.38 | 5.52E-14 | 3.23189  | 0.11915  | 0.04700  | 0.00189  | 0.26000  | 0.00193  | 0.00777  | 0.00009  | 0.94957  | 0.12197  |
| 1050 | 6.91 | 0.39 | 27.64 | 5.25E-14 | 3.38723  | 0.01158  | 0.04760  | 0.00043  | -0.01908  | 0.00104  | 0.00827  | 0.00017  | 0.97201  | 0.05254  |
| 1100 | 6.30 | 1.91 | 15.76 | 2.13E-14 | 5.41385  | 0.25307  | 0.03980  | 0.00210  | 0.28597  | 0.01409  | 0.01549  | 0.00019  | 1.26290  | 0.25858  |
| 1150 | 15.35 | 3.63 | 4.8 | 4.81E-15 | 43.30518  | 0.42471  | 0.03350  | 0.00234  | 3.58793  | 0.01501  | 0.14046  | 0.00086  | 2.08389  | 0.49430  |
| CN-3-Bt J = 0.003962 |
| 700 | 7.80 | 0.87 | 95.88 | 9.52E-16 | 4.18155  | 0.06683  | 0.05962  | 0.00108  | 0.00786  | 0.00102  | 0.01043  | 0.00035  | 1.09317  | 0.12192  |
| 750 | 7.75 | 0.62 | 1105.23 | 7.98E-16 | 1.36076  | 0.01963  | 0.04998  | 0.00129  | 0.00087  | 0.00013  | 0.00090  | 0.00029  | 1.08644  | 0.08684  |
| 800 | 7.24 | 1.05 | 149.45 | 1.14E-15 | 2.99787  | 0.14642  | 0.07131  | 0.00322  | 0.01757  | 0.00162  | 0.00669  | 0.00007  | 1.01506  | 0.14804  |
| 850 | 7.51 | 1.21 | 62.19 | 1.10E-15 | 5.81102  | 0.16994  | 0.06857  | 0.00006  | 0.00832  | 0.00315  | 0.01608  | 0.00003  | 1.05336  | 0.17011  |
| 900 | 8.20 | 2.64 | 10.91 | 1.45E-15 | 28.24325  | 0.13239  | 0.09095  | 0.00719  | 0.00178  | 0.00083  | 0.09166  | 0.00117  | 1.15035  | 0.37087  |
| 950 | 8.13 | 0.91 | 7.38 | 1.19E-15 | 41.17952  | 0.12798  | 0.07418  | 0.01210  | 0.01902  | 0.00555  | 0.13548  | 0.00003  | 1.14038  | 0.12839  |
| 1000 | 8.84 | 1.63 | 6.06 | 1.55E-15 | 50.03812  | 0.06559  | 0.09696  | 0.02093  | 0.01832  | 0.01777  | 0.16512  | 0.00075  | 1.23915  | 0.22987  |
| 1050 | 8.70 | 1.34 | 14.16 | 8.87E-16 | 22.09504  | 0.14421  | 0.05551  | 0.00011  | 0.00128  | 0.00098  | 0.07062  | 0.00041  | 1.21978  | 0.18897  |
| 1100 | 6.84 | 2.07 | 11.85 | 1.06E-15 | 25.89698  | 0.28390  | 0.06644  | 0.00818  | 0.00664  | 0.00465  | 0.08437  | 0.00021  | 0.95927  | 0.29090  |
| 1150 | 8.83 | 1.24 | 9.38 | 7.99E-16 | 32.74763  | 0.12630  | 0.05003  | 0.02180  | 0.00336  | 0.00773  | 0.10661  | 0.00040  | 1.23879  | 0.17374  |
| 1200 | 12.55 | 0.14 | 10.73 | 4.42E-16 | 29.31563  | 0.01733  | 0.02764  | 0.01023  | 0.01371  | 0.00985  | 0.09323  | 0.00003  | 1.76145  | 0.01989  |
| 1250 | 14.82 | 2.54 | 6.76 | 6.97E-16 | 45.80985  | 0.17632  | 0.04365  | 0.00236  | 0.00800  | 0.01320  | 0.14796  | 0.00105  | 2.08145  | 0.35801  |

Continued **Table S5**

|  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
| T(°C) | Age | ±Age | %40Ar\* | 39Ar(Moles) | 40/39Ar | ±40/39Ar | 38/39Ar | ±38/39Ar | 37/39Ar | ±37/39Ar | 36/39Ar | ±36/39Ar | 40Ar\*/39Ar | ±40Ar\*/39Ar |
| CN-4-Bt J = 0.003613 |
| 700 | 1.56 | 1.05 | 2.54 | 2.96E-14 | 8.57404  | 0.03044  | 0.21924  | 0.00039  | 20.39489  | 0.68959  | 0.03378  | 0.00046  | 0.22086  | 0.14873  |
| 750 | 8.25 | 0.98 | 89.74 | 6.98E-14 | 1.30392  | 0.12356  | 0.05952  | 0.05259  | 0.83979  | 0.15182  | 0.00066  | 0.00022  | 1.19283  | 0.43347  |
| 800 | 7.96 | 2.1 | 33.08 | 1.15E-13 | 3.39810  | 0.15432  | 0.19672  | 0.00852  | 7.42661  | 0.46638  | 0.00968  | 0.00085  | 1.14165  | 0.33896  |
| 850 | 9.64 | 0.9 | 64.84 | 2.07E-13 | 2.10883  | 0.04270  | 0.08974  | 0.00266  | 2.41894  | 0.00069  | 0.00314  | 0.00041  | 1.44568  | 0.20722  |
| 900 | 9.64 | 0.58 | 74.11 | 2.30E-13 | 1.83804  | 0.00055  | 0.09389  | 0.00336  | 7.34978  | 0.02679  | 0.00358  | 0.00028  | 1.22650  | 0.22695  |
| 950 | 10.23 | 0.39 | 44.91 | 1.03E-13 | 3.23298  | 0.03242  | 0.01036  | 0.00129  | 0.86523  | 0.01081  | 0.00624  | 0.00015  | 1.23169  | 0.04882  |
| 1000 | 10.38 | 0.91 | 30.46 | 3.98E-14 | 4.81859  | 0.07658  | 0.09714  | 0.00145  | 7.35300  | 0.02077  | 0.01331  | 0.00035  | 1.27317  | 0.13012  |
| 1050 | 10.23 | 1.46 | 25.05 | 2.81E-14 | 5.79091  | 0.19856  | 0.05651  | 0.00035  | 3.28322  | 0.14551  | 0.01555  | 0.00020  | 1.28490  | 0.20528  |
| 1100 | 9.07 | 0.95 | 27.7 | 4.70E-14 | 4.64810  | 0.00148  | 0.05238  | 0.00133  | 0.25632  | 0.00065  | 0.01142  | 0.00046  | 1.28758  | 0.13480  |
| 1150 | 10.06 | 1.21 | 29.57 | 4.62E-14 | 4.82897  | 0.06251  | 0.03601  | 0.00064  | 1.01249  | 0.00755  | 0.01176  | 0.00054  | 1.25614  | 0.17241  |
| 1200 | 12.68 | 1.56 | 16.7 | 1.84E-14 | 10.77854  | 0.04068  | 0.06069  | 0.00020  | 3.13239  | 0.16346  | 0.03121  | 0.00074  | 1.80321  | 0.22198  |
| 1250 | 16.32 | 3.95 | 6.42 | 3.66E-15 | 36.02121  | 0.51145  | 0.15280  | 0.01149  | 7.96647  | 0.68277  | 0.11621  | 0.00078  | 2.32298  | 0.56426  |
| CN-5-Bt J = 0.003729 |
| 650  | 4.98  | 2.10  | 4.55  | 2.05E-14 | 16.17559  | 0.21824  | 0.01114  | 0.04230  | 11.0521  | 0.38897  | 0.05522  | 0.00075  | 0.74072  | 0.31297  |
| 700 | 2.03 | 1.66 | 4.72 | 4.76E-14 | 6.34022  | 0.20811  | 0.08067  | 0.03287  | 10.6820  | 0.46273  | 0.02331  | 0.00043  | 0.30129  | 0.24736  |
| 750 | 10.71 | 0.93 | 27.2 | 5.22E-14 | 5.80587  | 0.09713  | 0.20020  | 0.00335  | 17.2651  | 0.41554  | 0.01896  | 0.00032  | 0.54000  | 0.35181  |
| 800 | 10.3 | 1.8 | 22.84 | 3.97E-14 | 6.70125  | 0.22394  | 0.00231  | 0.00509  | 5.05653  | 0.20572  | 0.01885  | 0.00050  | 0.80831  | 0.28405  |
| 850 | 9.63 | 1.01 | 17.12 | 3.12E-14 | 8.37343  | 0.05867  | 0.05103  | 0.00120  | 2.72724  | 0.04686  | 0.02420  | 0.00047  | 1.28436  | 0.14919  |
| 900 | 8.12 | 1.48 | 8.06 | 1.59E-14 | 14.96185  | 0.20364  | 0.06025  | 0.00084  | 4.17801  | 0.16649  | 0.04766  | 0.00029  | 1.32926  | 0.06967  |
| 950 | 10.61 | 2.15 | 6.85 | 1.14E-14 | 23.06463  | 0.25684  | 0.05111  | 0.00461  | 2.42700  | 0.01062  | 0.07334  | 0.00065  | 1.30144  | 0.06875  |
| 1000 | 9.48 | 2.41 | 26.45 | 2.10E-14 | 5.34272  | 0.06380  | 0.03129  | 0.00228  | 0.03355  | 0.00033  | 0.01328  | 0.00120  | 1.20540  | 0.18545  |
| 1050 | 7.82 | 2.1 | 14.99 | 3.02E-14 | 7.76670  | 0.27470  | 0.03195  | 0.00104  | 0.58428  | 0.00067  | 0.02248  | 0.00051  | 1.21881  | 0.16237  |
| 1100 | 8.15 | 1.32 | 19.94 | 4.92E-14 | 6.08742  | 0.02419  | 0.02905  | 0.00042  | 0.17751  | 0.00247  | 0.01652  | 0.00066  | 1.25913  | 0.19660  |
| 1150 | 15.12 | 2.19 | 23.89 | 2.87E-14 | 9.45022  | 0.03413  | 0.02738  | 0.00257  | 0.25769  | 0.00271  | 0.02439  | 0.00110  | 2.25770  | 0.32828  |
| 1200 | 18.58 | 7.76 | 5.01 | 3.91E-15 | 55.31857  | 1.14409  | 0.02791  | 0.01281  | 1.88484  | 0.03804  | 0.17831  | 0.00074  | 2.77558  | 1.16471  |

Continued **Table S5**

|  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
| T(°C) | Age | ±Age | %40Ar\* | 39Ar(Moles) | 40/39Ar | ±40/39Ar | 38/39Ar | ±38/39Ar | 37/39Ar | ±37/39Ar | 36/39Ar | ±36/39Ar | 40Ar\*/39Ar | ±40Ar\*/39Ar |
| CN-6-Bt J = 0.003729 |
| 700 | 9.04  | 7.68  | 0.70  | 1.52E-15 | 189.38902  | 1.04525  | 0.09764  | 0.00732  | 20.91187  | 0.22065  | 0.64206  | 0.00159  | 1.34769  | 1.14664  |
| 750 | 9.15  | 1.09  | 11.45  | 1.99E-14 | 11.77215  | 0.12088  | 0.16640  | 0.00175  | 18.25557  | 0.13026  | 0.04020  | 0.00037  | 1.36392  | 0.16243  |
| 800 | 6.77  | 0.52  | 5.15  | 1.36E-14 | 19.57797  | 0.07432  | 0.05007  | 0.00113  | 2.30653  | 0.01742  | 0.06345  | 0.00007  | 1.00884  | 0.07716  |
| 850 | 9.43  | 0.72  | 13.63  | 2.82E-14 | 10.28960  | 0.07075  | 0.05966  | 0.00062  | 3.68826  | 0.02832  | 0.03105  | 0.00027  | 1.40574  | 0.10701  |
| 900 | 9.01  | 0.29  | 18.00  | 4.45E-14 | 7.45428  | 0.01468  | 0.03539  | 0.00058  | 1.37262  | 0.02123  | 0.02103  | 0.00014  | 1.34307  | 0.04381  |
| 950 | 8.89  | 0.34  | 19.89  | 5.05E-14 | 6.65696  | 0.03389  | 0.02855  | 0.00218  | 0.33460  | 0.00157  | 0.01811  | 0.00013  | 1.32422  | 0.05042  |
| 1000 | 9.12  | 0.19  | 42.58  | 1.58E-13 | 3.19315  | 0.00415  | 0.02579  | 0.00009  | 0.04522  | 0.00021  | 0.00619  | 0.00010  | 1.35972  | 0.02879  |
| 1050 | 9.15  | 0.44  | 21.67  | 5.80E-14 | 6.28671  | 0.00296  | 0.02043  | 0.00030  | 0.56291  | 0.00566  | 0.01679  | 0.00022  | 1.36294  | 0.06625  |
| 1100 | 8.26  | 1.29  | 13.98  | 3.98E-14 | 8.79885  | 0.15361  | 0.01468  | 0.00027  | 0.46152  | 0.01356  | 0.02571  | 0.00040  | 1.23040  | 0.19322  |
| 1150 | 8.24  | 1.48  | 6.79  | 1.90E-14 | 18.06722  | 0.10694  | 0.01823  | 0.00304  | 1.74312  | 0.03577  | 0.05744  | 0.00066  | 1.22796  | 0.22136  |
| 1200 | 13.48  | 5.01  | 1.81  | 2.66E-15 | 109.57639  | 0.73455  | -0.00434  | 0.00649  | 19.26819  | 0.27701  | 0.36929  | 0.00052  | 2.01152  | 0.75078  |
| 1250 | 17.68  | 5.04  | 1.85  | 2.17E-15 | 141.84748  | 0.75019  | -0.04574  | 0.05169  | 8.04782  | 0.06976  | 0.47329  | 0.00032  | 2.64164  | 0.75620  |
| CN-7-Bt J = 0.003670 |
| 600 | 4.18 | 4.03 | 4.88 | 8.83E-15 | 13.02359  | 0.08337  | 0.14649  | 0.00150  | 17.45850  | 0.17350  | 0.04663  | 0.00208  | 0.64285  | 0.62060  |
| 650 | 1.07 | 0.2 | 4.54 | 5.47E-14 | 3.58967  | 0.03006  | 0.06597  | 0.00185  | 5.58173  | 0.00371  | 0.01309  | 0.00001  | 0.16354  | 0.03023  |
| 700 | 2.56 | 0.65 | 10.97 | 3.22E-14 | 3.58482  | 0.06090  | 0.03212  | 0.00110  | 1.03806  | 0.01795  | 0.01106  | 0.00027  | 0.39342  | 0.10020  |
| 750 | 2.79 | 0.64 | 9.54 | 2.90E-14 | 4.48908  | 0.09580  | 0.03604  | 0.00047  | 2.85700  | 0.04235  | 0.01449  | 0.00007  | 0.91809  | 0.09980  |
| 800 | 9.72 | 1.33 | 19.51 | 2.61E-14 | 7.65942  | 0.20467  | 0.03827  | 0.00038  | 0.83538  | 0.03062  | 0.02106  | 0.00005  | 1.67618  | 0.20593  |
| 850 | 8.58 | 1.76 | 5 | 1.40E-14 | 26.24434  | 0.23087  | 0.06528  | 0.00029  | 7.85033  | 0.06890  | 0.08647  | 0.00049  | 1.65936  | 0.27049  |
| 900 | 9.65 | 0.97 | 19.61 | 1.79E-14 | 7.56675  | 0.14563  | 0.02018  | 0.00236  | 0.42402  | 0.00207  | 0.02068  | 0.00013  | 1.59025  | 0.15062  |
| 950 | 10.18 | 1 | 37.43 | 6.81E-14 | 4.18542  | 0.09674  | 0.02003  | 0.00057  | 0.41742  | 0.00113  | 0.00895  | 0.00041  | 1.56710  | 0.15409  |
| 1000 | 9.48 | 0.51 | 32.89 | 3.84E-14 | 4.43577  | 0.05015  | 0.02423  | 0.00017  | 0.43368  | 0.01445  | 0.01017  | 0.00021  | 1.58229  | 0.08229  |
| 1050 | 9.96 | 0.7 | 35.18 | 4.51E-14 | 4.35457  | 0.04497  | 0.02021  | 0.00008  | 0.61631  | 0.01334  | 0.00970  | 0.00033  | 1.74176  | 0.11184  |
| 1100 | 9.61 | 1.35 | 19.56 | 1.63E-14 | 7.56469  | 0.20556  | 0.02254  | 0.00333  | 0.45342  | 0.00816  | 0.02069  | 0.00010  | 1.76934  | 0.20879  |
| 1150 | 18.74 | 5.24 | 4.79 | 3.28E-15 | 60.19689  | 0.67783  | 0.04377  | 0.00914  | 3.86930  | 0.09984  | 0.19498  | 0.00152  | 2.89125  | 0.81282  |

Continued **Table S5**

|  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
| T(°C) | Age | ±Age | %40Ar\* | 39Ar(Moles) | 40/39Ar | ±40/39Ar | 38/39Ar | ±38/39Ar | 37/39Ar | ±37/39Ar | 36/39Ar | ±36/39Ar | 40Ar\*/39Ar | ±40Ar\*/39Ar |
| CN-8-Bt J = 0.003663 |
| 9.53 | 0.75 | 19.96 | 1.11E-14 | 7.23980  | 0.08841  | 0.03596  | 0.00644  | 1.32431  | 0.00360  | 0.01994  | 0.00024  | 1.44654  | 0.11400  | 0.14664  |
| 9.32 | 0.60 | 35.63 | 4.45E-14 | 3.96835  | 0.07981  | 0.02600  | 0.00020  | 0.39326  | 0.00848  | 0.00873  | 0.00015  | 0.93126  | 0.39322  | 0.16243  |
| 10.73 | 0.19 | 61.12 | 5.64E-14 | 2.65983  | 0.00596  | 0.04450  | 0.00036  | 2.60426  | 0.00858  | 0.00418  | 0.00009  | 0.84563  | 0.41333  | 0.07716  |
| 10.29 | 0.36 | 33.13 | 3.41E-14 | 4.70805  | 0.04820  | 0.03046  | 0.00011  | 1.92254  | 0.00685  | 0.01115  | 0.00008  | 1.75242  | 0.03772  | 0.10701  |
| 11.29 | 0.94 | 10.63 | 1.65E-14 | 16.11983 | 0.13731  | 0.02636  | 0.00169  | 0.93266  | 0.00775  | 0.04898  | 0.00014  | 1.71429  | 0.14318  | 0.04381  |
| 11.04 | 1.15 | 8.22 | 1.24E-14 | 20.38621 | 0.03981  | 0.03669  | 0.00481  | 0.34113  | 0.00220  | 0.06339  | 0.00058  | 1.63373  | 0.17855  | 0.05042  |
| 10.44 | 1.27 | 5.3 | 9.32E-15 | 29.88021 | 0.01603  | 0.02856  | 0.01121  | 0.03915  | 0.00237  | 0.09574  | 0.00065  | 1.52812  | 0.19188  | 0.02879  |
| 10.23 | 0.88 | 12.83 | 2.58E-14 | 12.10155 | 0.01724  | 0.02572  | 0.00418  | 0.63889  | 0.00021  | 0.03585  | 0.00045  | 1.67860  | 0.13374  | 0.06625  |
| 11.33 | 0.88 | 12.84 | 2.25E-14 | 13.38409 | 0.02296  | 0.02350  | 0.00240  | 1.32792  | 0.00271  | 0.03982  | 0.00045  | 1.71954  | 0.13462  | 0.19322  |
| 19.03 | 1.31 | 15.44 | 1.38E-14 | 18.71985 | 0.12546  | 0.01066  | 0.00398  | 1.85063  | 0.01813  | 0.05404  | 0.00053  | 2.34661  | 0.46678  | 0.22136  |
| 20.71 | 2.92 | 3.68 | 2.73E-15 | 84.87292 | 0.44264  | 0.01921  | 0.01237  | 14.4399  | 0.08394  | 0.28054  | 0.00019  | 3.15160  | 0.44627  | 0.75078  |
| 22.74 | 3.78 | 7.49 | 7.30E-15 | 46.14711 | 0.03030  | 0.07494  | 0.00033  | 3.10614  | 0.00400  | 0.14529  | 0.00196  | 3.48591  | 0.57996  | 0.75620  |
| CN-9-Bt J = 0.003774 |
| 650 | 4.61 | 2.61 | 2.99 | 1.19E-14 | 22.29081  | 0.29166  | 0.22020  | 0.00189  | 25.19732  | 0.63126  | 0.07998  | 0.00083  | 0.67784  | 0.38463  |
| 700 | 5.49 | 0.67 | 11.15 | 4.04E-14 | 7.15517  | 0.02890  | 0.12553  | 0.00015  | 17.05436  | 0.20024  | 0.02611  | 0.00032  | 0.80700  | 0.09888  |
| 750 | 7.13 | 0.46 | 34.61 | 9.26E-14 | 2.99624  | 0.05621  | 0.14578  | 0.00064  | 17.39342  | 0.47060  | 0.01132  | 0.00002  | 1.04881  | 0.06777  |
| 800 | 6.20 | 0.52 | 18.99 | 6.63E-14 | 4.75852  | 0.05869  | 0.10157  | 0.00001  | 13.33518  | 0.21491  | 0.01664  | 0.00015  | 0.91156  | 0.07607  |
| 850 | 12.29 | 0.59 | 24.34 | 4.37E-14 | 7.38643  | 0.01793  | 0.09870  | 0.00056  | 11.53946  | 0.21121  | 0.02202  | 0.00028  | 1.81150  | 0.08684  |
| 900 | 14.04 | 1.62 | 15.14 | 2.26E-14 | 13.63467  | 0.16183  | 0.05752  | 0.00016  | 4.17730  | 0.05994  | 0.04026  | 0.00060  | 2.07050  | 0.23910  |
| 950 | 13.00 | 0.68 | 13.17 | 2.17E-14 | 14.52918  | 0.09949  | 0.06279  | 0.00043  | 1.51404  | 0.01269  | 0.04308  | 0.00006  | 1.91553  | 0.10089  |
| 1000 | 13.53 | 0.76 | 18.31 | 3.04E-14 | 10.88260  | 0.11046  | 0.02236  | 0.00118  | 1.80823  | 0.02834  | 0.03055  | 0.00008  | 1.99488  | 0.11277  |
| 1050 | 14.00 | 0.48 | 29 | 5.17E-14 | 7.11537  | 0.00485  | 0.02252  | 0.00184  | 1.18114  | 0.00866  | 0.01739  | 0.00024  | 2.06486  | 0.07057  |
| 1100 | 13.12 | 0.94 | 63.89 | 1.29E-13 | 3.02577  | 0.02301  | 0.01495  | 0.00040  | 0.25706  | 0.00076  | 0.00374  | 0.00047  | 1.93347  | 0.13953  |
| 1150 | 14.19 | 0.83 | 37.58 | 7.09E-14 | 5.56589  | 0.03319  | 0.02259  | 0.00017  | 0.66998  | 0.00527  | 0.01192  | 0.00040  | 2.09250  | 0.12314  |
| 1200 | 11.47 | 2.11 | 17.23 | 2.17E-14 | 9.79887  | 0.22162  | 0.05592  | 0.00028  | 1.91410  | 0.07037  | 0.02794  | 0.00074  | 1.69071  | 0.31141  |
| 1250 | 18.98 | 2.62 | 4.12 | 4.74E-15 | 67.60676  | 0.04215  | 0.12403  | 0.00372  | 7.52280  | 0.04567  | 0.22137  | 0.00131  | 2.80201  | 0.38868  |

Continued **Table S5**

|  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
| T(°C) | Age | ±Age | %40Ar\* | 39Ar(Moles) | 40/39Ar | ±40/39Ar | 38/39Ar | ±38/39Ar | 37/39Ar | ±37/39Ar | 36/39Ar | ±36/39Ar | 40Ar\*/39Ar | ±40Ar\*/39Ar |
| CN-10-Bt J = 0.003885 |
| 650 | 3.53 | 1.96 | 3.01 | 1.83E-14 | 16.54348  | 0.04445  | 0.19778  | 0.00342  | 16.09766  | 0.06371  | 0.05864  | 0.00094  | 0.50356  | 0.28001  |
| 700 | 6.67 | 0.57 | 21.5 | 6.06E-14 | 4.42645  | 0.00643  | 0.05326  | 0.00186  | 3.61413  | 0.01292  | 0.01272  | 0.00028  | 0.37372  | 0.13538  |
| 750 | 13.89 | 0.98 | 82.59 | 1.01E-13 | 2.38721  | 0.11094  | 0.11100  | 0.00076  | 13.79766  | 0.27334  | 0.00512  | 0.00029  | 0.69417  | 0.24186  |
| 800 | 14.23 | 0.62 | 20.18 | 2.41E-14 | 10.00881  | 0.01972  | 0.10397  | 0.00035  | 13.93220  | 0.07643  | 0.03079  | 0.00030  | 1.97444  | 0.05724  |
| 850 | 14.78 | 1.05 | 12.75 | 1.34E-14 | 16.53370  | 0.06473  | 0.08587  | 0.00693  | 6.15465  | 0.04584  | 0.05046  | 0.00046  | 2.11698  | 0.15060  |
| 900 | 13.85 | 1.37 | 8.48 | 1.02E-14 | 23.32102  | 0.00011  | 0.05091  | 0.00802  | 4.02900  | 0.01609  | 0.07330  | 0.00067  | 1.98311  | 0.19692  |
| 950 | 14.37 | 0.62 | 11.48 | 1.46E-14 | 17.88984  | 0.03271  | 0.04118  | 0.01085  | 2.97171  | 0.01254  | 0.05437  | 0.00028  | 2.05831  | 0.08942  |
| 1000 | 13.71 | 0.44 | 24.13 | 3.41E-14 | 8.13487  | 0.00899  | 0.03281  | 0.00228  | 0.14302  | 0.00032  | 0.02090  | 0.00021  | 1.99325  | 0.04030  |
| 1050 | 13.94 | 1.21 | 13.1 | 1.55E-14 | 15.20883  | 0.11690  | 0.02763  | 0.00325  | 3.38208  | 0.03827  | 0.04562  | 0.00043  | 1.99714  | 0.17357  |
| 1100 | 14.49 | 2.08 | 7.22 | 7.35E-15 | 28.65641  | 0.07487  | 0.04898  | 0.00365  | 6.21071  | 0.02930  | 0.09164  | 0.00098  | 2.07637  | 0.29911  |
| 1150 | 18.86 | 3.2 | 6.75 | 5.32E-15 | 40.05620  | 0.27860  | 0.09877  | 0.00636  | 1.73000  | 0.00932  | 0.12686  | 0.00125  | 2.70511  | 0.46202  |
| 1200 | 16.77 | 3.37 | 8.62 | 7.48E-15 | 27.85809  | 0.48354  | 0.00502  | 0.00198  | 0.41715  | 0.00665  | 0.08623  | 0.00015  | 2.40339  | 0.48549  |
| CN-10-Kfs J = 0.003430 |
| 700 | 10.08 | 0.34 | 77.12 | 1.24E-13 | 2.11697  | 0.03989  | 0.01445  | 0.00041  | 0.17291  | 0.00111  | 0.00166  | 0.00013  | 1.63289  | 0.05551  |
| 750 | 6.61 | 0.21 | 67.53 | 2.55E-13 | 1.58543  | 0.00687  | 0.01426  | 0.00036  | 0.06398  | 0.00033  | 0.00174  | 0.00011  | 1.07068  | 0.03351  |
| 800 | 7.30 | 0.46 | 57.73 | 7.61E-14 | 2.04620  | 0.01652  | 0.01380  | 0.00079  | 0.28064  | 0.00149  | 0.00298  | 0.00024  | 1.18145  | 0.07387  |
| 850 | 8.10 | 0.61 | 50.05 | 5.91E-14 | 2.62155  | 0.02197  | 0.01024  | 0.00098  | 0.59186  | 0.00125  | 0.00457  | 0.00033  | 1.31246  | 0.09910  |
| 900 | 11.35 | 0.97 | 65.83 | 5.32E-14 | 2.79565  | 0.04712  | 0.01165  | 0.00267  | -0.11204  | 0.00108  | 0.00318  | 0.00051  | 1.84028  | 0.15737  |
| 950 | 11.35 | 0.64 | 64.87 | 7.49E-14 | 2.83563  | 0.01117  | 0.01296  | 0.00144  | 0.20457  | 0.00200  | 0.00340  | 0.00035  | 1.83977  | 0.10401  |
| 1000 | 11.47 | 0.84 | 55.42 | 8.73E-14 | 3.35562  | 0.02160  | 0.01187  | 0.00120  | 0.17974  | 0.00094  | 0.00509  | 0.00046  | 1.85975  | 0.13718  |
| 1050 | 11.46 | 0.53 | 62.13 | 8.86E-14 | 2.98965  | 0.03512  | 0.01201  | 0.00088  | 0.14364  | 0.00013  | 0.00385  | 0.00026  | 1.85773  | 0.08558  |
| 1100 | 11.56 | 0.29 | 76.4 | 2.34E-13 | 2.45232  | 0.00881  | 0.01251  | 0.00005  | 0.31399  | 0.00881  | 0.00202  | 0.00016  | 1.87394  | 0.04739  |
| 1150 | 11.59 | 0.28 | 84.73 | 2.24E-13 | 2.21710  | 0.00534  | 0.01369  | 0.00008  | 0.21977  | 0.00105  | 0.00118  | 0.00015  | 1.87885  | 0.04593  |
| 1200 | 11.53 | 0.37 | 85.53 | 1.07E-13 | 2.18508  | 0.04608  | 0.01217  | 0.00117  | 0.20413  | 0.00119  | 0.00110  | 0.00013  | 1.86912  | 0.06005  |
| 1250 | 11.16 | 0.86 | 53.63 | 2.58E-14 | 3.37056  | 0.02107  | 0.01233  | 0.00381  | 0.85942  | 0.00415  | 0.00550  | 0.00047  | 1.80852  | 0.14022  |

**Table S6.** Results of apatite (U-Th)/He dating

|  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
| Sample | Mass(μg) | ar (μm) | bl (μm) | U (ppm) | Th (ppm) | Sm (ppm) | Th/U | 4He (ncc) | cFt | Raw Age (Ma) | Corrected Age (Ma) | Error (±1**σ)** | Mean Age (Ma) | Standard Error | Elevation (m) |
|
| CN2-1 | 7.8 | 56.64 | 246.21 | 47.9 | 29.3 | 127.3 | 0.61 | 0.0155 | 0.76 | 0.3 | 0.4 | 0 | 1.0 | 0.4 | 2970 |
| CN2-2 | 6.5 | 47.18 | 294.54 | 19.5 | 6.2 | 93.8 | 0.32 | 0.0178 | 0.72 | 1.1 | 1.4 | 0.1 |
| CN2-3 | 7.8 | 52.86 | 280.15 | 28.1 | 8.1 | 117.5 | 0.29 | 0.0407 | 0.75 | 1.4 | 1.8 | 0.1 |
| CN2-4 | 8.6 | 61.05 | 231.20 | 30.4 | 14.7 | 80.8 | 0.48 | 0.0116 | 0.77 | 0.3 | 0.4 | 0 |
| CN3-1 | 6.0 | 45.94 | 285.24 | 85.9 | 36.9 | 80.9 | 0.43 | 0.1116 | 0.72 | 1.6 | 2.2 | 0.1 | 1.9 | 0.2 | 3166 |
| CN3-2 | 19.6 | 75.86 | 342.74 | 45.3 | 2.3 | 108.4 | 0.05 | 0.1805 | 0.82 | 1.6 | 2 | 0.1 |
| CN3-3 | 8.0 | 56.2 | 255.27 | 153 | 18.8 | 151.9 | 0.12 | 0.1722 | 0.76 | 1.1 | 1.4 | 0.1 |
| CN3-4 | 12.9 | 69.56 | 268.85 | 47.7 | 21.2 | 123.8 | 0.44 | 0.1251 | 0.80 | 1.5 | 1.8 | 0.1 |
| CN6-1 | 35.5 | 90.74 | 434.31 | 17 | 7.9 | 45.4 | 0.46 | 0.2000 | 0.85 | 2.5 | 2.8 | 0.1 | 2.0 | 0.3 | 3800 |
| CN6-2 | 9.2 | 61.23 | 248.47 | 44.8 | 22.7 | 128.3 | 0.51 | 0.0602 | 0.77 | 1.1 | 1.3 | 0.1 |
| CN6-3 | 25.1 | 85.92 | 342.16 | 21.9 | 14.7 | 100.8 | 0.67 | 0.1299 | 0.84 | 1.7 | 2 | 0.1 |
| CN6-4 | 18.6 | 70.47 | 377.39 | 14.8 | 7.6 | 67.9 | 0.51 | 0.0577 | 0.81 | 1.5 | 1.8 | 0.1 |
| CN7-1 | 6.6 | 53.34 | 232.06 | 83.2 | 15.3 | 26.6 | 0.18 | 0.1236 | 0.74 | 1.8 | 2.3 | 0.1 | 2.0 | 0.1 | 3945 |
| CN7-2 | 11.0 | 62.80 | 280.52 | 52.7 | 9.2 | 30.9 | 0.17 | 0.1133 | 0.78 | 1.5 | 1.9 | 0.1 |
| CN7-3 | 10.8 | 60.46 | 297.69 | 79.3 | 7.1 | 25.9 | 0.09 | 0.1724 | 0.78 | 1.6 | 2 | 0.1 |
| CN7-4 | 12.1 | 66.24 | 278.12 | 62.5 | 15.6 | 27.9 | 0.25 | 0.1314 | 0.79 | 1.3 | 1.7 | 0.1 |
| CN8-1 | 8.9 | 55.32 | 293.91 | 16.2 | 2.3 | 9.7 | 0.14 | 0.0279 | 0.76 | 1.5 | 2 | 0.1 | 1.8 | 0.2 | 4103 |
| CN8-2 | 15.6 | 70.78 | 314.49 | 19.8 | 2.9 | 14.5 | 0.15 | 0.0613 | 0.81 | 1.6 | 1.9 | 0.1 |
| CN8-3 | 17.1 | 75.15 | 304.68 | 24.5 | 27.7 | 24.2 | 1.13 | 0.0803 | 0.81 | 1.2 | 1.5 | 0.1 |
| CN9-1 | 6.1 | 55.48 | 198.42 | 16.8 | 7.1 | 90.8 | 0.43 | 0.0811 | 0.74 | 5.9 | 7.7 | 0.3 | 5.0 | 2.7 | 4295 |
| CN9-2 | 8.0 | 59.06 | 231.90 | 8.1 | 5.7 | 77.5 | 0.71 | 0.0167 | 0.76 | 1.8 | 2.3 | 0.1 |
| CN10-1 | 2.4 | 41.10 | 145.41 | 98.8 | 34.9 | 142.5 | 0.35 | 0.0946 | 0.65 | 3.0 | 4.3 | 0.2 | 6.8 | 0.8 | 4526 |
| CN10-2 | 3.0 | 41.20 | 178.99 | 157.8 | 144.3 | 169.9 | 0.91 | 0.2872 | 0.66 | 4.1 | 5.8 | 0.3 |
| CN10-3 | 4.1 | 44.66 | 207.08 | 21.1 | 21.7 | 139.9 | 1.03 | 0.0981 | 0.69 | 7.5 | 10.3 | 0.5 |

ar - radius; bl - length; cFt - alpha ejection correction of Farley et al., 1996.

**Table S7.** Results of zircon (U-Th)/He dating

|  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
| Sample | Mass (μg) | ar (μm) | bl  (μm) | U (ppm) | Th (ppm) | Th/U | c[eU] (ppm) | 4He (ncc) | dFt | Corrected age (Ma) | Error (±1**σ)** | Mean Age (Ma) | Standard Error | Elevation (m) |
|
| CN2-1 | 8.9 | 44.0 | 310.5 | 1119.0 | 160.7 | 0.14 | 1156.8 | 2.653 | 0.78 | 2.1  | 0.1  | 2.4  | 0.1  | 2970  |
| CN2-2 | 13.5 | 72.2 | 244.1 | 311.7 | 120.0 | 0.38 | 339.9 | 1.342 | 0.84 | 2.4  | 0.1  |
| CN2-3 | 17.4 | 55.3 | 386.8 | 594.5 | 105.3 | 0.18 | 619.3 | 3.407 | 0.83 | 2.6  | 0.2  |
| CN2-4 | 19.4 | 59.7 | 379.6 | 839.2 | 78.4 | 0.09 | 857.7 | 4.716 | 0.84 | 2.3  | 0.1  |
| CN8-1 | 11.6 | 49.6 | 325.7 | 601.0 | 147.1 | 0.24 | 635.5 | 2.293 | 0.81 | 2.6  | 0.2  | 2.7  | 0.3  | 4103  |
| CN8-2 | 15.5 | 48.3 | 428.0 | 355.8 | 122.5 | 0.34 | 384.6 | 2.580 | 0.81 | 3.6  | 0.2  |
| CN8-3 | 11.6 | 41.4 | 423.1 | 332.1 | 58.0 | 0.17 | 345.7 | 1.233 | 0.78 | 2.5  | 0.2  |
| CN8-4 | 9.3 | 42.0 | 344.2 | 518.9 | 74.1 | 0.14 | 536.3 | 1.309 | 0.78 | 2.2  | 0.1  |

ar - radius; bl - length; c[eU] - effective uranium concentration (U ppm+0.235 Th ppm);

dFt - alpha ejection correction of Farley et al., 1996.

**Table S8.** Estimates on horizontal extension magnitude for N-S trending rifts

|  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- |
| Number in Figure 1b | Name | Extension magnitude (km) | Displacement of fault (km) | Exhumation amount (km) | Dip angle (°) | Basis | References |
| b | North Lunggar | 15-20 |  |  |  | Undeformed hanging-wall strata on opposite sides of the range, a maximum extension | Sundell et al., 2013 |
| c | South Lunggar | 19-21 |  |  |  | Net extension constrained by the thermokinematic modeling | Styron et al., 2013 |
| d | Lopukangri | 7 | 10 |  | 45 | Restoring the Great Counter Thrust (GCT, cut by rift) in a direction parallel the Lopukangri rift | Murphy et al., 2010; Sanchez et al., 2013  |
| e | Tangra Yum Co | 9.2 | 13 |  | 45 | Long-term slip rate of >1.0 mm/yr and the 13 Ma of onset time | Dewane et al., 2006 |
| f | Xainza | <17 |  | <10 | 29 | Vertical exhumation and dip angle | Sundell et al., 2013 |
| h | Nyainqentanghla | 7-21 | 8-26 |  | 35 | 8 km fault slip based on the down-slope distance of shear zone or 21-26 km of fault slip based on thermobarometric data  | Kapp et al., 2005; Harrison et al., 1995 |
| i | Leo Pargil | 31-43 |  | 18-25 | 30 | Activity history of fault | Langille et al., 2012; Thiede et al., 2006  |
| j | Gurla Mandhata | 26-30  | 30-35 |  | 30 | Fault slip constrained by the thermokinematic modeling | Murphy and Copeland, 2005; McCallister et al., 2014 |
| l | Kung Co  | <5 |  | <8 | 60 | Exhumation of granite | Lee et al., 2011 |
| n | Yadong-Gulu | <3-4 |  |  |  |  | Armijo et al., 1986 |
| o | Cona  | 2-5 |  | 4-8 | 60 | Initiation age of fault | This study |

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