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

Shuang Bian1,2, Junfeng Gong1,2\*, Andrew V. Zuza3, Rong Yang1,2, Yuntao Tian4, Jianqing Ji5, Hanlin Chen1,2, Qinqin Xu6, Lin Chen7, Xiubin Lin1,2, Xiaogan Cheng1,2, Jiyao Tu5, Xiangjiang Yu8

1 Key Laboratory of Geoscience Big Data and Deep Resource of Zhejiang Province, School of Earth Sciences, Zhejiang University, Hangzhou 310027, China

2 Research Center for Structures in Oil and Gas Bearing Basins, Ministry of Education, Hangzhou 310027, China

3 Nevada Bureau of Mines and Geology, University of Nevada, Reno, Nevada 89557, USA

4 School of Earth Sciences and Engineering, Sun Yat-sen University, Guangzhou 510275, China

5 School of Earth and Space Sciences, Peking University, Beijing 100871, China

6 Institute of Geology, Chinese Academy of Geological Sciences, Beijing 100037, China

7 Institute of Geology and Geophysics, Chinese Academy of Sciences, Beijing 100029, China

8 College of Earth Sciences, Jilin University, Changchun 130061, China

\* Corresponding author: Junfeng Gong (jfgong@zju.edu.cn)

**Contents of Supplementary Text**

1. Models for east-west extension

2. Initiation of E-W extension

3. Testable Predictions from the working hypothesis

4. Fig. S1

5. Tables S1 to S8

**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.

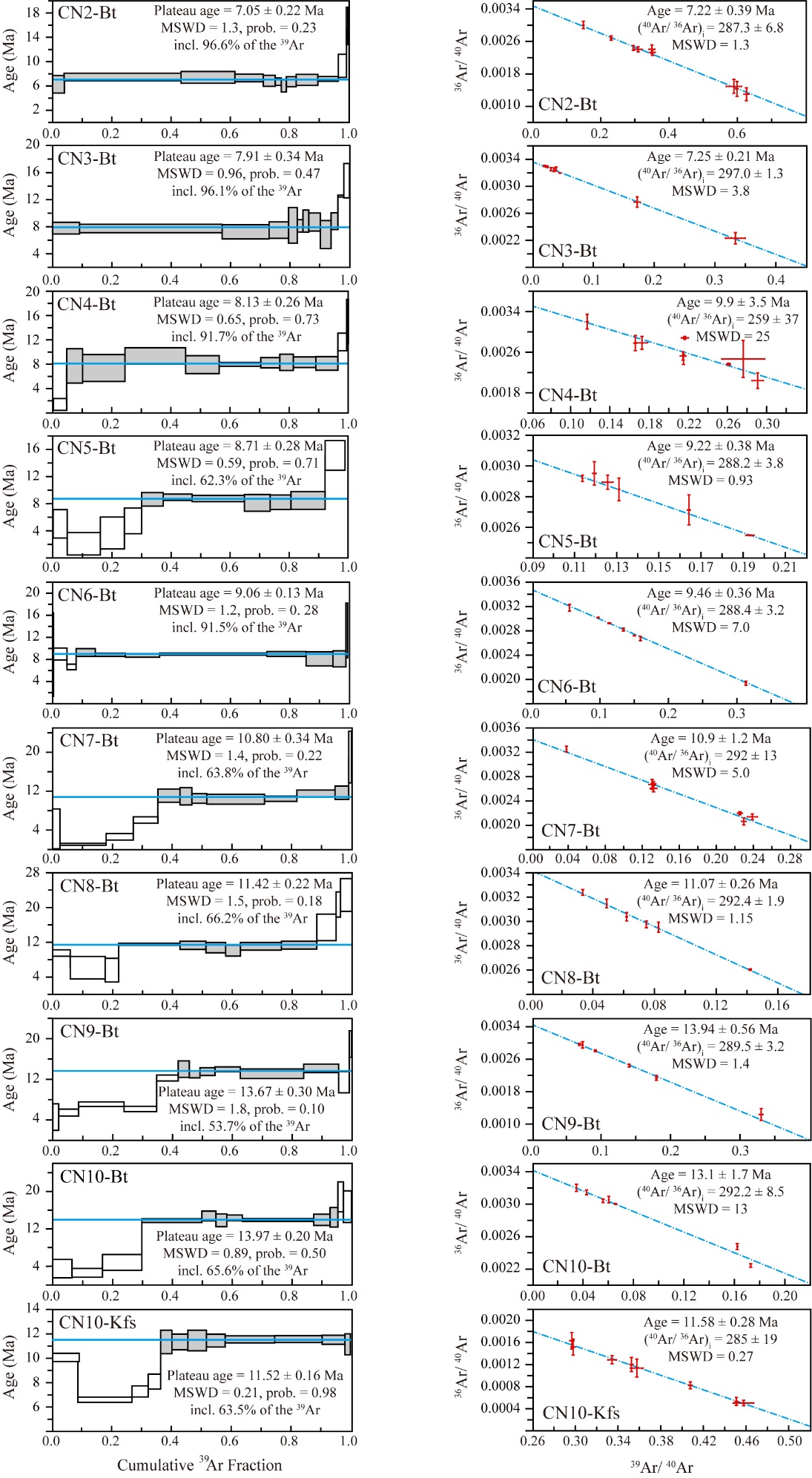


Fig. S1. Age spectra (left) and inverse isochrons (right) for 40Ar/39Ar thermochronology.

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

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| Model | Extent of E-W extension | Temporal pattern  of rifts | | Extension magnitude  pattern |
| 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 in  Fig. 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 |

**References**

Aitchison, J.C., Ali, J.R., Chan, A., Davis, A.M., Lo, C.H., 2009. Tectonic implications of felsic tuffs within the Lower Miocene Gangrinboche conglomerates, southern Tibet. J. Asian Earth Sci. 34, 287-297. https://doi.org/10.1016/j.jseaes.2008.05.008.

Armijo, R., Tapponnier, P., Mercier, J.L., Han, T.L., 1986. Quaternary extension in southern Tibet: Field observations and tectonic implications. J. Geophys. Res. 91, 13803-13872. https://doi.org/10.1029/JB091iB14p13803.

Baranowski. J., Armbruster. J.G., Seeber. L., Molnar, P., 1984. Focal depths and fault-plane solutions of earthquakes and active tectonics of the Himalaya. J. Geophys. Res. 89, 6918-6928. https://doi.org/10.1029/JB089iB08p06918.

Bendick, R., Bilham, R., 2001. How perfect is the Himalayan arc? Geology 29, 791. https://doi.org/10.1130/0091-7613(2001)0292.0.CO;2.

Bhattacharyya, K., Mitra, G., Kwon, S., 2015. Geometry and kinematics of the Darjeeling-Sikkim Himalaya, India: implications for the evolution of the Himalayan fold-thrust belt. J. Asian Earth Sci. 113, 778-796. https://doi.org/10.1016/j.jseaes.2015.09.008.

Bischoff, S.H., Flesh, L.M., 2018. Normal faulting and viscous buckling in the Tibetan Plateau induced by a weak lower crust. Nat. Commun. 9, 4952. https://doi.org/10.1038/s41467-018-07312-9.

Bischoff, S.H., Flesh, L.M., 2019. Impact of lithospheric strength distribution on India‐Eurasia deformation from 3‐D geodynamic models. J. Geophys. Res. Solid Earth 124, 1084-1105. https://doi.org/10.1029/2018JB015704.

Blisniuk, P.M., Hacker, B.R., Glodny, J., Ratschbacher, L., Bi, S.W., Wu, Z.H., McWilliams, M.O., Calvert, A., 2001. Normal faulting in central Tibet since at least 13.5 Myr ago. Nature 412, 628-632. https://doi.org/10.1038/35088045.

Booth, A.L., 2004. U-Pb zircon constraints on the tectonic evolution of southeastern Tibet, Namche Barwa Area. Am. J. Sci. 304, 889-929. https://doi.org/10.2475/ajs.304.10.889.

Buer, N. J. V., Jagoutz, O., Upadhyay, R., Guillong, M., 2015. Mid-crustal detachment beneath western Tibet exhumed where conjugate Karakoram and Longmu-Gozha Co faults intersect. Earth Planet. Sci. Lett. 413, 144-157. https://doi.org/10.1016/j.epsl.2014.12.053.

Chen, J., Xu, J., Wang, B., Kang, Z., Jie, L., 2010. Origin of Cenozoic alkaline potassic volcanic rocks at KonglongXiang, Lhasa terrane, Tibetan Plateau: Products of partial melting of a mafic lower-crustal source? Chem. Geol. 273, 286-299. https://doi.org/10.1016/j.chemgeo.2010.03.003.

Chen, J.L., Xu, J.F., Kang, Z.Q., Wang, B.D., 2006. Origin of the Miocene Bugasi group volcanic rocks in the Cuoqin County, western Tibetan plateau. Acta Petrol. Sin. 22, 585-594 (in Chinese, with English abstract).

Chen, J.L., Xu, J.F., Zhao, W.X., Dong, Y.H., Wang, B.D., Kang, Z.Q., 2011. Geochemical variations in Miocene adakitic rocks from the western and eastern Lhasa terrane: Implications for lower crustal flow beneath the Southern Tibetan Plateau. Lithos 125, 928-939. https://doi.org/10.1016/j.lithos.2011.05.006.

Chen, Y., Li, W., Yuan, X., Badal, J. Teng, J., 2015. Tearing of the Indian lithospheric slab beneath southern Tibet revealed by SKS-wave splitting measurements. Earth Planet. Sci. Lett. 413, 13-24. https://doi.org/10.1016/j.epsl.2014.12.041.

Chung, S.L., Chu, M.F., Ji, J., O’Reilly, S.Y., Pearson, N.J., Liu, D., Lee, T.Y., Lo, C.H., 2009. The nature and timing of crustal thickening in Southern Tibet: Geochemical and zircon Hf isotopic constraints from postcollisional adakites. Tectonophysics 477, 36-48. https://doi.org/10.1016/j.tecto.2009.08.008.

Chung, S.L., Liu, D., Ji, J., Chu, M.F., Lee, H.Y., Wen, D.J., Lo, C.H., Lee, T.Y., Qian, Q., Zhang, Q., 2003. Adakites from continental collision zones: Melting of thickened lower crust beneath southern Tibet. Geology 31, 1021-1024.

Cochran, J. R., 1990. Himalayan uplift, sea level, and the record of Bengal Fan sedimentation at the ODP leg 116 sites. Proc. ODP. Sci. Results 116, 397-414.

Coleman, M., Hodges, K., 1995. Evidence for Tibetan Plateau uplift before 14 Myr ago from a new minimum age for east-west extension. Nature 374, 49-52. https://doi.org/10.1038/374049a0.

Coulon, C., Maluski, H., Bollinger, C., Wang, S., 1986. Mesozoic and Cenozoic volcanic rocks from central and southern Tibet: 39Ar/40Ar dating, petrological characteristics and geodynamical significance. Earth Planet. Sci. Lett. 79, 281-302. https://doi.org/10.1016/0012-821X(86)90186-X.

DeCelles, P.G., Kapp, P., Quade, J., Gehrels, G.E., 2011. Oligocene-Miocene Kailas basin, southwestern Tibet: Record of postcollisional upper-plate extension in the Indus-Yarlung suture zone. Geol. Soc. Am. Bull. 123, 1337-1362. https://doi.org/10.1130/B30258.1.

DeCelles, P.G., Robinson, D.M., Quade, J., Ojha, T.P., Garzione, C.N., Copeland, P., Upreti, B.N., 2001. Stratigraphy, structure, and tectonic evolution of the Himalayan fold-thrust belt in western Nepal. Tectonics 20, 487-509. https://doi.org/10.1029/2000tc001226.

Dewane, T.J., Stockli, D.F., Hager, C., Taylor, M., Ding, L., Lee, J., Wallis, S., 2006. Timing of Cenozic E-W extension in the Tangra Yum Co-Kung Co rift, south-central Tibet. AGU Fall Meet. Abstr. 87.

Dewey, J.F., 1988. Extensional collapse of orogens. Tectonics 7, 1123-1139. https://doi.org/10.1029/TC007i006p01123.

Ding, L., Kapp, P., Zhong, D.L., Deng, W.M., 2003. Cenozoic Volcanism in Tibet: Evidence for a Transition from Oceanic to Continental Subduction. J. Petrol. 44, 1833-1865. https://doi.org/10.1093/petrology/egg061.

Ding, L., Yue, Y.H, Cai, F.L., Xu, X.X., Zhang, Q.H., Lai, Q.Z., 2006. 40Ar/39Ar geochronology, geochemical and Sr-Nd-O isotopic characteristics of the high-Mg ultrapotassic rocks in Lhasa block of Tibet: implications in the onset time and depth of NS-striking rift system. Acta Geol. Sin. 80, 1252-1261.

Edwards, M.A., Harrison, T.M., 1997. When did the roof collapse? Late Miocene north-south extension in the high Himalaya revealed by Th-Pb monazite dating of the Khula Kangri granite. Geology 25, 543-546. https://doi.org/10.1130/0091-7613(1997)0252.3.CO;2.

England, P., Houseman, G., 1988. The mechanics of the Tibetan Plateau. Phil. Trans. R. Soc. Lond. 326, 301-320. https://doi.org/10.1098/rsta.1988.0089.

England, P., Houseman, G., 1989. Extension during continental convergence, with application to the Tibetan Plateau. J. Geophys. Res. 94, 17561-17579. https://doi.org/10.1029/JB094iB12p17561.

Farley, K.A., Wolf, R.A., Silver, L.T., 1996. The effects of long alpha-stopping distances on (U-Th)/He ages. Geochim. Cosmochim. Acta 60, 4223-4229. https://doi.org/10.1016/S0016-7037(96)00193-7.

Gao, Y.F., Yang, Z.S., Santosh, M., Hou, Z.Q., Wei, R.H., Tian, S.H., 2010. Adakitic rocks from slab melt-modified mantle sources in the continental collision zone of southern Tibet. Lithos 119, 651-663. https://doi.org/10.1016/j.lithos.2010.08.018.

Garzione, C.N., DeCelles, P.G., Hodkinson, D.G., Ojha, T.P., Upreti, B.N., 2003. East-west extension and Miocene environmental change in the southern Tibetan Plateau, Thakkhola Graben, central Nepal. Geol. Soc. Am. Bull. 115, 3-20. https://doi.org/10.1130/0016-7606(2003)1152.0.CO;2.

Garzione, C.N., Dettman, D.L., Quade, J., DeCelles, P.G., Butler, R.F., 2000. High times on the Tibetan Plateau: Paleoelevation of the Thakkhola graben, Nepal. Geology 28, 339-342. https://doi.org/10.1130/0091-7613(2000)28<339:HTOTTP>2.0.CO;2.

Guo, Z.F., Wilson, F., 2018. Late Oligocene-early Miocene transformation of post-collisional magmatism in Tibet. Geology 47, 776-780. https://doi.org/10.1130/G46147.1.

Guo, Z.F., Wilson, M., Zhang, M.L., Cheng, Z.H., Zhang, L.H., 2015. Post-collisional ultrapotassic mafic magmatism in south Tibet: Products of partial melting of pyroxenite in the mantle wedge induced by roll-back and delamination of the subducted Indian continental lithosphere slab. J. Petrol. 56, 1365-1406. https://doi.org/10.1093/petrology/egv040.

Guo, Z.F., Wilson, M., Zhang, M.L., Cheng, Z.H., Zhang, L.H., 2013. Post-collisional, K-rich mafic magmatism in south Tibet: constraints on Indian slab-to-wedge transport processes and plateau uplift. Contrib. Mineral. Petrol. 165, 1311-1340. https://doi.org/10.1007/s00410-013-0860-y.

Hager, C., Stockli, D.F., Dewane, T.J., Gehrels, G., Ding, L., 2009. Anatomy and crustal evolution of the central Lhasa terrane (S-Tibet) revealed by investigations in the Xainza rift. Geophys. Res. Abstr. 11, EGU2009-11346-1.

Haproff, P.J., Zuza, A.V., Yin, A., 2018. West-directed thrusting south of the eastern Himalayan syntaxis indicates clockwise crustal flow at the indenter corner during the India-Asia collision. Tectonophysics 722, 277-285. https://doi.org/10.1016/j.tecto.2017.11.001.

Harrison, T.M., Copeland, P., Kidd, W.S.F., Lovera, O.M., 1995. Activation of the Nyainqentanghla Shear Zone: Implications for uplift of the southern Tibetan Plateau. Tectonics 14, 658-676. https://doi.org/10.1029/95tc00608.

Harrison, T.M., Copeland, P., Kidd, W.S.F., Yin, A., 1992. Raising Tibet. Science 255, 1663-1670. https://doi.org/10.1126/science.255.5052.1663.

Harrison, T.M., Yin, A., Grove, M., Lovera, O.M., Ryerson, F.J., Zhou, X., 2000. The Zedong Window: A record of superposed Tertiary convergence in southeastern Tibet. J. Geophys. Res. Solid Earth 105, 19211-19230. https://doi.org/10.1029/2000JB900078.

Hintersberger, E., Thiede, R.C., Strecker, M.R., Hacker, B.R., 2010. East-west extension in the NW Indian Himalaya. Geol. Soc. Am. Bull. 122, 1499-1515. https://doi.org/10.1130/B26589.1.

Hou, Z.Q., Gao, Y.F., Qu, X.M., Rui, Z.Y., Mo, X.X., 2004. Origin of adakitic intrusives generated during mid-Miocene east-west extension in southern Tibet. Earth Planet. Sci. Lett. 220, 139-155. https://doi.org/10.1016/S0012-821X(04)00007-X.

Hou, Z.Q., Zheng, Y.C., Yang, Z.M., Rui, Z.,Y. Zhao, Z.,D. Jiang, S.H., Qu, X.M., Sun, Q.Z., 2013. Contribution of mantle components within juvenile lower-crust to collisional zone porphyry Cu systems in Tibet. Miner. Deposita 48, 173-192. https://doi.org/10.1007/s00126-012-0415-6.

Hu, P., Nie, F.J., Jiang, S.H., Liu, Y, Zhang, W.Y., 2006. Zircon SHRIMP U-Pb age of the Songtuoga intrusion in Mayum gold deposit District, Xizang (Tibet) and its geological significances.Geol. Rev. 52, 276-282 (in Chinese with English abstract).

Hu, W., Tian, S., Yang, Z., Zhang, Z., 2012. Petrogenesis of Miocene Chajiasi potassic rocks in western Lhasa block, Tibetan Plateau: Constraints from lithogeochemistry, Geochronology and Sr-Nd isotopes. Mineral Deposits 31, 813-830 (in Chinese with English abstract).

Ji, W.Q., Wu, F.Y., Chung, S.L., Li, J.X., Liu, C.Z., 2009. Zircon U-Pb geochronology and Hf isotopic constraints on petrogenesis of the Gangdese batholith, southern Tibet. Chem. Geol. 262, 229-245. https://doi.org/10.1016/j.chemgeo.2009.01.020.

Jiang, S.H., Nie, F.J., Hu, P., Lai, X.R., Liu, Y.F., 2009. Mayum: an orogenic gold deposit in Tibet, China. Ore Geol. Rev. 36, 160-173. https://doi.org/10.1016/j.oregeorev.2009.03.006.

Jiang, S.H., Nie, F.J., Hu, P., Liu, Y., 2006. 40Ar-39Ar age and geochemical features of the Mayum adakitic porphry in Tibet. Acta Geol. Sin. 22(3), 603-611.

Jiang, Z.Q., Wang, Q., Wyman, D.A., Li, Z.X., Yang, J.H., Shi, X.B., Ma, L., Tang, G.J., Gou, G.N., Jia, X.H., Guo, H.F., 2014. Transition from oceanic to continental lithosphere subduction in southern Tibet: Evidence from the Late Cretaceous-Early Oligocene (~91-30Ma) intrusive rocks in the Chanang-Zedong area, southern Gangdese. Lithos 196-197, 213-231. https://doi.org/10.1016/j.lithos.2014.03.001.

Kali, E., Leloup, P.H., Arnaud, N., Maheo, G., Liu, D.Y., Boutonnet, E., Van der Woerd, J., Liu, X.H., Liu-Zeng, J., Li, H.B., 2010. Exhumation history of the deepest central Himalayan rocks Ama Drime range: Key pressure-temperature-deformation-time constraints on orogenic models. Tectonics 29, TC2014. https://doi.org/10.1029/2009TC002551.

Kapp, J.L.D., Harrison, T.M., Kapp, P., Grove, M., Lovera, O. M., Ding, L., 2005. Nyainqentanglha Shan: A window into the tectonic, thermal, and geochemical evolution of the Lhasa block, southern Tibet. J. Geophys. Res. 110, 653-669. https://doi.org/10.1029/2004JB003330.

Kapp, P., Murphy, M.A., Yin, A., Harrison, T.M. , Ding, L., Guo, J.H., 2003. Mesozoic and Cenozoic tectonic evolution of the Shiquanhe area of western Tibet. Tectonics 22, 1029. https://doi.org/10.1029/2001TC001332.

Kapp, P., Taylor, M., Stockli, D., Ding, L., 2008. Development of active low-angle normal fault systems during orogenic collapse: Insight from Tibet. Geology 36, 7-10. https://doi.org/10.1130/G24054A.1.

Kind, R., Yuan, X., 2010. Seismic images of the biggest crash on earth. Science 329, 1479-1480. https://doi.org/10.1126/science.1191620.

King, J., Harris, N., Argles, T., Parrish, R., Charlier, B., Sherlock, S., Zhang, H.F., 2007. First field evidence of southward ductile flow of Asian crust beneath southern Tibet. Geology 35, 727-730.

Klootwijk, C.T., Conaghan, P.J., Powell, C.M., 1985. The Himalayan arc: Large-scale continental subduction, oroclinal bending and back-arc spreading. Earth Planet. Sci. Lett. 75, 167-183. https://doi.org/10.1016/0012-821X(85)90099-8.

Kroop, D., 1991. Onset of monsoonal related upwelling in the western Arabian Sea as revealed by planktonic foraminifers. Proc. ODP. Sci. Res. 117, 257-263.

Langille, J.M., Jessup, M.J., Cottle, J., Lederer, G., Ahmad, T., 2012. Timing of metamorphism, melting and exhumation of the Leo Pargil dome, northwest India. J. Metamorphic Geol. 30, 769-791. https://doi.org/10.1111/j.1525-1314.2012.00998.x.

Larson, K.L., Kellett, D.A., Cottle, J.M., Camacho, A., Brubacher, A.D., 2019. Mid-Miocene initiation of E-W extension and recoupling of the Himalaya. Terra Nova 00, 1-8. https://doi.org/10.1111/ter.12443.

Leary, R., Orme, D.A., Laskowski, A.K., Decelles, P.G., Kapp, P., Carrapa, B., Dettinger, M., 2016. Along-strike diachroneity in deposition of the Kailas Formation in central southern Tibet: Implications for Indian slab dynamics. Geosphere 12, 1-26. https://doi.org/10.1130/ges01325.1.

Lee, J., Hager, C., Wallis, S. R., Stockli, D. F., Whitehouse, M. J., Aoya, M., Wang, Y., 2011. Middle to late Miocene extremely rapid exhumation and thermal reequilibration in the Kung Co rift, southern Tibet. Tectonics 30, 120-130. https://doi.org/10.1029/2010TC002745.

Li, C., Hilst, R.D.V.D., Meltzer, A.S., Engdahl, E.R., 2008. Subduction of the Indian lithosphere beneath the Tibetan Plateau and Burma. Earth Planet. Sci. Lett. 274, 157-168. https://doi.org/10.1016/j.epsl.2008.07.016.

Li, D., Yin, A., 2008. Orogen-parallel, active left-slip faults in the Eastern Himalaya: Implications for the growth mechanism of the Himalayan Arc. Earth Planet. Sci. Lett. 274, 258-267. https://doi.org/10.1016/j.epsl.2008.07.043.

Li, J.T., Song, X.D., 2018. Tearing of Indian mantle lithosphere from high-resolution seismic images and its implications for lithosphere deformation in southern Tibet. Proc. Natl. Acad. Sci. 115, 8296-8300. https://doi.org/10.1073/pnas.1717258115.

Li, J.X., Qin, K.Z., Li, G.M., Xiao, B., Chen, L., Zhao, J.X., 2011. Post-collisional ore-bearing adakitic porphyries from Gangdese porphyry copper belt, southern Tibet: Melting of thickened juvenile arc lower crust. Lithos 126, 265-277. https://doi.org/10.1016/j.lithos.2011.07.018.

Liang, X., Chen, Y., Tian, X., Chen, Y.J., Ni, J., Gallegos, A., Klemperere, S.L., Wang, M.L., Xu, T., Sun, C.Q., Si, S.K., Lan, H.Q., Teng, J.W., 2016. 3D imaging of subducting and fragmenting Indian continental lithosphere beneath southern and central Tibet using body-wave finite-frequency tomography. Earth Planet. Sci. Lett. 443, 162-175. https://doi.org/10.1016/j.epsl.2016.03.029.

Liu, D., Zhao, Z., Zhu, D.C., Niu, Y., DePaolo, D.J., Harrison, T.M., Mo, X., Dong, G., Zhou, S., Sun, C., Zhang, Z., Liu, J., 2014b. Postcollisional potassic and ultrapotassic rocks in southern Tibet: Mantle and crustal origins in response to India-Asia collision and convergence. Geochim. Cosmochim. Acta 143, 207-231. https://doi.org/10.1016/j.gca.2014.03.031.

Liu, D., Zhao, Z., Zhu, D.C., Niu, Y., Harrison, T.M., 2014a. Zircon xenocrysts in Tibetan ultrapotassic magmas: Imaging the deep crust through time. Geology 42, 43-46. https://doi.org/10.1130/G34902.1.

Liu, D., Zhao, Z.D., Zhu, D.C., Wang, Q., Sui, Q.L., Liu, Y.S., Hu, Z.C., Mo, X.X., 2011. The petrogenesis of post-collisional potassic-ultrapotassic rocks in Xungba basin, western Lhasa terrane: constraints from zircon U-Pb geochronology and geochemistry. Acta Petrol. Sin. 27, 2045-2059.

Liu, M., Cui, X.J., Liu, F.T., 2004. Cenozoic rifting and volcanism in eastern China: a mantle dynamic link to the Indo-Asian collision? Tectonophysics 393, 29-42. https://doi.org/10.1016/j.tecto.2004.07.029.

Liu, M., Yang, Y.Q., 2003. Extensional collapse of the Tibetan Plateau: Results of three-dimensional finite element modeling. J. Geophys. Res., 108, 2361. https://doi.org/10.1029/2002jb002248.

Long, S., Mcquarrie, N., Tobgay, T., Grujic, D., 2011. Geometry and crustal shortening of the Himalayan fold-thrust belt, eastern and central Bhutan. Geol. Soc. Am. Bull. 123, 1427-1447. https://doi.org/10.1130/b30203.1.

Mahéo, G., Leloup, P. H., Valli, F., Lacassin, R., Arnaud, N., Paquette, J.L., Fernandez, A., Haibing, L., Farley, K.A., Tapponnier, P., 2007. Post 4 Ma initiation of normal faulting in southern Tibet. Constraints from the Kung Co half graben. Earth Planet. Sci. Lett. 256, 233-243. https://doi.org/10.1016/j.epsl.2007.01.029.

McCaffrey, R., Nabelek, J., 1998. Role of oblique convergence in the active deformation of the Himalayas and southern Tibet plateau. Geology 26, 691-694. https://doi.org/10.1130/0091-7613(1998)026<0691:ROOCIT>2.3.CO;2.

McCallister, A.T., Taylor, M.H., Murphy, M.A, Styron, R.H., Stockli, D.F., 2014. Thermochronologic constraints on the late Cenozoic exhumation history of the Gurla Mandhata metamorphic core complex, Southwestern Tibet. Tectonics 33, 27-52. https://doi.org/10.1002/2013TC003302.

Mechie, J., Sobolev, S.V., Ratschbacher, L., Babeyko, A.Y., Bock, G., Jones, A.G., Nelson, K.D., Solon, K.D., Brown, L.D., Zhao, W., 2004. Precise temperature estimation in the Tibetan crust from seismic detection of the α-β, quartz transition. Geology 32, 601-604. https://doi.org/10.1130/G20367.1.

Meng, J., Gilder, S.A., Li, Y.L., Wang, C.S., Liu, T., 2020. Expanse of Greater India in the late Cretaceous. Earth Planet. Sci. Lett. 542, 1-11. https://doi.org/10.1016/j.epsl.2020.116330.

Mercier, J.L., Armijo, R., Tapponnier, P., Carey-Gailhardis, E., Lin, H.T., 1987. Change from Late Tertiary compression to Quaternary extension in southern Tibet during the India-Asia collision. Tectonics 6, 275-304. https://doi.org/10.1029/tc006i003p00275.

Miller, C., Schuster, R., Tzli, U.K., Frank, W., Purtscheller, F., 1999. Post-Collisional Potassic and Ultrapotassic Magmatism in SW Tibet: Geochemical and Sr-Nd-Pb-O Isotopic Constraints for Mantle Source Characteristics and Petrogenesis. J. Petrol. 40, 1399-1424.

Molnar, P., England, P., Martinod, J., 1993. Mantle dynamics, uplift of the Tibetan plateau, and the Indian monsoon. Rev. Geophys. 31, 357-396. https://doi.org/10.1029/93rg02030.

Molnar, P., Lyon-Caent, H., 1989. Fault plane solutions of earthquakes and active tectonics of the Tibetan Plateau and its margins. Geophys. J. Int. 99, 123-154. https://doi.org/10.1111/j.1365-246X.1989.tb02020.x.

Molnar, P., Tapponnier, P., 1978. Active tectonics of Tibet. J. Geophys. Res. 83, 5361-5375. https://doi.org/10.1029/JB083iB11p05361.

Murphy, M.A., Copeland, P., 2005. Transtensional deformation in the central Himalaya and its role in accommodating growth of the Himalayan orogeny. Tectonics 24, TC4012. https://doi.org/10.1029/2004tc001659.

Murphy, M.A., Sanchez, V., Taylor, M.H., 2010. Syncollisional extension along the India-Asia suture zone, south-central Tibet: Implications for crustal deformation of Tibet. Earth Planet. Sci. Lett. 290, 233-243. https://doi.org/10.1016/j.epsl.2009.11.046.

Murphy, M.A., Saylor, J.E., Ding, L., 2009. Late Miocene topographic inversion in southwest Tibet based on integrated paleoelevation reconstructions and structural history. Earth Planet. Sci. Lett. 282, 0-9. https://doi.org/10.1016/j.epsl.2009.01.006.

Murphy, M.A., Yin, A., Kapp, P., Harrison, T.M., Manning, C.E., Ryerson, F.J., Ding, L., Guo, J.H., 2002. Structural evolution of the Gurla Mandhata detachment system, southwest Tibet: Implications for the eastward extent of the Karakoram fault system. Geol. Soc. Am. Bull. 114, 428-447. https://doi.org/10.1130/0016-7606(2002)1142.0.CO;2.

Nábělek, J., Hetényi, G., Vergne, J., Sapkota, S., Kafle, B., Jiang, M., et al., 2009. Underplating in the Himalaya-Tibet collision zone revealed by the HI-CLIMB experiment. Science 325, 1371-1374. https://doi.org/10.1126/science.1167719.

Nelson, K. D., Zhao, W., Brown, L. D., Kuo, J., Che, J., Liu, X. W., Klemperer, S. L., Makovsky, Y., Meissner, R., Mechie, J., Kind, R., Wenzel, F., Ni, J., Nabelek, J., Chen L.S., Tan, H.D., Wei, W.B., Jones, A.G., Booker, J., Unsworth, M., Kidd, W. S. F., Hauck, M., Alsdorf, D., Ross, A., Cogan, M., Wu, C.D., Sandvol, E., Edwards, M., 1996. Partially molten middle crust beneath southern Tibet: synthesis of thesis of project INDEPTH results. Science 274, 1684-1688. https://doi.org/10.1126/science.274.5293.1684.

Nomade, S., Renne, P.R., Mo, X., Zhao, Z., Zhou, S., 2004. Miocene volcanism in the Lhasa block, Tibet: spatial trends and geodynamic implications. Earth Planet. Sci. Lett. 221, 227-243. https://doi.org/10.1016/S0012-821X(04)00072-X.

Northrup, C.J., Royden, L.H., Burchfiel, B.C., 1995. Motion of the Pacific plate relative to Eurasia and its potential relation to Cenozoic extension along the eastern margin of Eurasia. Geology 23, 719-722. https://doi.org/10.1130/0091-7613(1995)023<0719:motppr>2.3.co;2.

Pan, F.B., Zhang, H.F., Harris, N., Xu, W.C., Guo, L., 2012. Oligocene magmatism in the eastern margin of the east Himalayan syntaxis and its implication for the India-Asia post-collisional process. Lithos 154, 181-192. https://doi.org/10.1016/j.lithos.2012.07.004.

Pang, Y.J., Zhang, H., Gerya, T.V., Liao, J., Cheng, H.H., Shi, Y.L., 2018. The mechanism and dynamics of N-S rifting in southern Tibet: Insight from 3-D thermomechanical modeling. J. Geophys. Res. Solid Earth. 123, 859-877. https://doi.org/10.1002/2017JB014011.

Pei, S.P., Liu, H.B., Bai, L., Liu, Y.B., Sun, Q., 2016. High-resolution seismic tomography of the 2015 Mw7.8 Gorkha earthquake, Nepal: Evidence for the crustal tearing of the Himalayan rift. Geophys. Res. Lett. 43, 9045-9052. https://doi.org/10.1002/2016GL069808.

Peng, M., Jiang, M., Li, Z.H., Xu, Z.Q., Zhu, L.P., Chan, W., 2016. Complex Indian subduction style with slab fragmentation beneath the eastern Himalayan syntaxis revealed by teleseismic P-wave tomography. Tectonophysics 667, 77-86. https://doi.org/10.1016/j.tecto.2015.11.012.

Qu, X.M., Hou, Z.Q., Li, Z.Q., 2003. The 40Ar/39Ar ages of the ore-bearing porphyries in Gangdese copper belt and their geological significances. Acta Geol. Sin. 77, 245-252 (in Chinese, with English abstract).

Ratschbacher, L., Frisch, W., Liu, G.H., Chen, C.S., 1994. Distributed deformation in southern and western tibet during and after the india-asia collision. J. Geophys. Res. Solid Earth 99, 19917-19945. https://doi.org/10.1029/94JB00932.

Ratschbacher, L., Krumrei, I., Blumenwitz, M., Staiger, M., Gloaguen, R., Miller, B.V., Samson, S.D., Edwards, M.A., Appel, E., 2011. Rifting and strike-slip shear in central Tibet and the geometry, age and kinematics of upper crustal extension in Tibet. Geol. Soc. London Spec. Publ. 353, 127-163. https://doi.org/10.1144/SP353.8.

Ravikant, V., Wu, F.Y., Ji, W.Q., 2009. Zircon U-Pb and Hf isotopic constraints on petrogenesis of the Cretaceous-Tertiary granites in eastern Karakoram and Ladakh, India. Lithos 110, 153-166. https://doi.org/10.1016/j.lithos.2008.12.013.

Ren, J., Tamaki, K., Li, S., Junxia, Z., 2002. Late Mesozoic and Cenozoic rifting and their dynamic setting in eastern China. Tectonophysics 344, 175-205. https://doi.org/10.1016/S0040-1951(01)00271-2.

Replumaz, A., Capitanio, F.A., Guillot, S., Negredo, A.M., Villaseñor, A., 2014. The coupling of Indian subduction and Asian continental tectonics. Gondwana Res. 26, 608-626. https://doi.org/10.1016/j.gr.2014.04.003.

Replumaz, A., Negredo, A. M., Villaseñor, A., Guillot. S., 2010. Indian continental subduction and slab break-off during Tertiary collision. Terra Nova 22, 290-296. https://doi.org/10.1111/j.1365-3121.2010.00945.x.

Royden, L.H., Burchfiel, B.C., Van, D.H.R.D., 2008. The geological evolution of the Tibetan plateau. Science 321, 1054-1058. https://doi.org/10.1126/science.1155371.

Sanchez, V.I., Murphy, M.A., Robinson, A.C., Lapen, T.J., Heizler, M.T., 2013. Tectonic evolution of the India-Asia suture zone since Middle Eocene time, Lopukangri area, south-central Tibet. J. Asian Earth Sci. 62, 205-220. https://doi.org/10.1016/j.jseaes.2012.09.004.

Saylor, J.E., De Celles, P.G., Quade, J., 2010. Climate-driven environmental change in the Zhada basin, southwestern Tibet Plateau. Geosphere 6, 74-92. https://doi.org/10.1130/GES00507.S2.

Saylor, J.E., Quade, J., Dellman, D.L., DeCelles, P.G., Kapp, P.A., Ding, L., 2009. The late Miocene through present paleoelevation history of southwestern Tibet. Am. J. Sci. 309, 1-42. https://doi.org/10.2475/01.2009.01.

Schill, E., Appel, E., Zeh, O., Singh, V.K., Gautam, P., 2001. Coupling of late-orogenic tectonics and secondary pyrrhotite remanences: Towards a separation of different rotation processes and quantiﬁcation of rotational underthrusting in the western Himalaya (northern India). Tectonophysics 337, 1-21. https://doi.org/10.1016/S0040-1951(01)00113-5.

Searle, M., 1995. The rise and fall of Tibet. Nature 374, 17-18. https://doi.org/10.1038/374017a0.

Seeber, L., Armbruster, J.G., 1984. Some elements of continental subduction along the Himalayan front. Tectonophysics 105, 263-278. https://doi.org/10.1016/0040-1951(84)90207-5.

Seeber, L., Pêcher, A., 1998. Strain partitioning along the Himalayan arc and the Nanga Parbat antiform. Geology 26, 791-794. https://doi.org/10.1130/0091-7613(1998)026<0791:SPATHA>2.3.CO;2.

Spicer, R.A., Harris, N.B.W., Widdowson, M., Herman, A.B., Guo, S., Valdes, P.J., Wolfe, J.A., Kelley, S.P., 2003. Constant elevation of southern Tibet over the past 15 million years. Nature 421, 622-624. https://doi.org/10.1038/nature01356.

Stockli, D., Taylor, M., Yin, A., Harrison, T. M., D'Andrea, J., Kapp, P., Ding, L., 2002. Late Miocene-Pliocene inception of E-W extension in Tibet as evidenced by apatite (U-Th)/He data. Geol. Soc. Am. Abstr. Programs 34, 411.

Styron, R. H., Taylor, M. H., Murphy, M. A., 2011. Oblique convergence, arc-parallel extension, and the role of strike-slip faulting in the High Himalaya. Geosphere 7, 582-596. https://doi.org/10.1130/GES00606.1. https://doi.org/10.1130/GES00606.1.

Styron, R., Taylor, M., Sundell, K., 2015. Accelerated extension of Tibet linked to the northward underthrusting of Indian crust. Nat. Geosci. 8, 131-134. https://doi.org/10.1038/ngeo2336.

Styron, R.H., Taylor, M.H., Sundell, K.E., Stockli, D.F., Oalmann, J.A.G., Möller, A., McCallister, A.T., Liu, D.L., Ding, L., 2013. Miocene initiation and acceleration of extension in the South Lunggar rift, western Tibet: Evolution of an active detachment system from structural mapping and (U-Th)/He thermochronology. Tectonics 32, 880-907. https://doi.org/10.1002/tect.20053.

Sun, C.G., Zhao, Z.D., Mo, X.X., Zhu, D.C., Dong, G.C., Zhou, S., Dong, X., Xie, G.G., 2008. Geochemistry and origin of the Miocene Sailipu ultrapotassic rocks on western Lhasa block, Tibetan Plateau. Acta Petrol. Sin. 23, 2715-2726.

Sundell, K.E., Taylor, M.H., Styron, R.H., Stockli, D.F., Kapp, P., Hager, C., Liu, D., Ding, L., 2013. Evidence for constriction and Pliocene acceleration of east-west extension in the North Lunggar rift region of west central Tibet. Tectonics 32, 1454-1479. https://doi.org/10.1002/tect.20086.

Taylor, M., Yin, A., Ryerson, F.J., Kapp, P., Ding, L., 2003. Conjugate strike-slip faulting along the Bangong-Nujiang suture zone accommodates coeval east-west extension and north-south shortening in the interior of the Tibetan Plateau. Tectonics 22, 1044. https://doi.org/10.1029/2002tc001361.

Thiede, R.C., Arrowsmith, J.R., Bookhagen, B., Mc Williams, M., Sobel, E.R., Strecker, M.R., 2006. Dome formation and extension in the Tethyan Himalaya, Leo Pargil, northwest India. Geol. Soc. Am. Bull. 118, 635-650. https://doi.org/10.1130/B25872.1.

Turner, S., Hawkesworth, C., Liu, J., Rogers, N., Kelley, S., Calsteren, P.V., 1993. Timing of Tibetan uplift constrained by analysis of volcanic rocks. Nature 364, 50-54. https://doi.org/10.1038/364050a0.

Wang, Q., Wyman, D.A., Xu, J., Dong, Y., Vasconcelos, P.M., Pearson, N., Wan, Y., Dong, H., Li, C., Yu, Y., 2008. Eocene melting of subducting continental crust and early uplifting of central Tibet: evidence from central-western Qiangtang high-K calc-alkaline andesites, dacites and rhyolites. Earth Planet. Sci. Lett. 272, 158-171.

Webb, A.A.D., Guo, H., Clift, P.D., Husson, L., Müller, T., Costantino, D., Yin, A., Xu, Z.Q., Cao, H., Wang, Q., 2017. The Himalaya in 3D: Slab dynamics controlled mountain building and monsoon intensification. Lithosphere 9, 637-651. https://doi.org/10.1130/L636.1.

Williams, H., Turner, S., Kelley, S., Harris, N., 2001. Age and composition of dikes in Southern Tibet: New constraints on the timing of east-west extension and its relationship to postcollisional volcanism. Geology 29, 339-342. https://doi.org/10.1130/0091-7613(2001)029<0339:AACODI>2.0.CO;2.

Williams, H.M., 2004. Nature of the Source Regions for Post-collisional, Potassic Magmatism in Southern and Northern Tibet from Geochemical Variations and Inverse Trace Element Modelling. J. Petrol. 45, 555-607. https://doi.org/10.1093/petrology/egg094.

Woodruff, W.H., Horton, B.K., Kapp, P., Stockli, D.F., 2013. Late Cenozoic evolution of the Lunggar extensional basin, Tibet: Implications for basin growth and exhumation in hinterland plateaus. Geol. Soc. Am. Bull. 125, 343-358. https://doi.org/10.1130/B30664.1

Xiao, L., Wang, C.Z., Pirajno, F., 2007. Is the underthrust India lithosphere split beneath the Tibetan Plateau? Int. Geol. Rev. 49, 90-98. https://doi.org/10.2747/0020-6814.49.1.90

Xie, G.G., Zou, A.J., Yuan, J.Y., Li, X.Y., Liao, S.P., Tang, F.L., Huang, C.G., Chen, Z.H., Xu, Z.F., 2004. New results and major progress in regional geological survey of the Boindoi District and Comai sheets. Geol. Bull. China 23, 498-505 (in Chinese with English abstract).

Xu, W.C., Zhang, H.F., Guo, L., Yuan, H.L., 2010. Miocene high Sr/Y magmatism, south Tibet: Product of partial melting of subducted Indian continental crust and its tectonic implication. Lithos 114, 293-306. https://doi.org/10.1016/j.lithos.2009.09.005.

Xu, Z.Q., Wang, Q., Pêcher, A., Liang, F.H., Qi, X.X., Cai, Z.H., Li, H.Q., Zeng, L.S., Cao, H., 2013. Orogen-parallel ductile extension and extrusion of the greater Himalaya in the late Oligocene and Miocene. Tectonics 32, 191-https://doi.org/191-215.10.1002/tect.20021.

Yang, Y., Liu, M., 2013. The Indo-Asian continental collision: A 3-D viscous model. Tectonophysics 606, 198-211. https://doi.org/10.1016/j.tecto.2013.06.032.

Yin, A., 2000. Mode of Cenozoic east-west Extension in Tibet suggests a common origin of rifts in Asia during Indo-Asian collision. J. Geophys. Res. Solid Earth 105, 21745-21759. https://doi.org/10.1029/2000JB900168.

Yin, A., 2010. Cenozoic tectonic evolution of Asia: A preliminary synthesis. Tectonophysics 488, 293-325. https://doi.org/10.1016/j.tecto.2009.06.002.

Yin, A., Harrison, T.M., Ryerson, F.J., Wenji, C., Kidd, W.S.F., Copeland, P., 1994. Tertiary structural evolution of the Gangdese Thrust System, southeastern Tibet. J. Geophys. Res. Solid Earth 99, 18175-18201. https://doi.org/10.1029/94JB00504.

Yin, A., Kapp, P.A., Murphy, M.A., Manning, C.E., Harrison, T.M., Grove, M., Ding, L., Deng, X.G., Wu, C.M., 1999. Significant late Neogene east-west extension in northern Tibet. Geology 27, 787-790. https://doi.org/10.1130/0091-7613(1999)027<0787:SLNEWE>2.3.CO;2.

Yin, A., Taylor, M.H., 2011. Mechanics of V-shaped conjugate strike-slip faults and the corresponding continuum mode of continental deformation. Geol. Soc. Am. Bull. 123, 1798-1821. https://doi.org/10.1130/b30159.1.

Zhang, H.F., Harris, N., Guo, L., Xu, W.C., 2010. The significance of Cenozoic magmatism from the western margin of the eastern syntaxis, southeast Tibet. Contrib. Mineral. Petrol. 160, 83-98. https://doi.org/10.1007/s00410-009-0467-5.

Zhang, J., Guo, L., 2007. Structure and geochronology of the southern Xainza-Dinggye rift and its relationship to the south Tibetan detachment system. J. Asian Earth Sci. 29, 722-736. https://doi.org/10.1016/j.jseaes.2006.05.003

Zhang, L., Guo, Z., Zhang, M., Cheng, Z., Sun, Y., 2015. Post-collisional potassic magmatism in the eastern Lhasa terrane, south Tibet: Products of partial melting of mélanges in a continental subduction channel. Gondwana Res., 41, 9-28. https://doi.org/10.1016/j.gr.2015.11.007.

Zhang, L.Y., Ducea, M.N., Ding, L., Pullen, A., Kapp, P., Hoffman, D., 2014. Southern Tibetan Oligocene-Miocene adakites: A record of Indian slab tearing. Lithos 210-211, 209-223. https://doi.org/10.1016/j.lithos.2014.09.029.

Zheng, Y.C., Hou, Z.Q., Li, Q.Y., Sun, Q.Z., Liang, W., Fu, Q., Li, W., Huang, K.X., 2012a. Origin of Late Oligocene adakitic intrusives in the southeastern Lhasa terrane: Evidence from in situ zircon U-Pb dating, Hf-O isotopes, and whole-rock geochemistry. Lithos 148, 296-311. https://doi.org/10.1016/j.lithos.2012.05.026.

Zheng, Y.C., Hou, Z.Q., Li, W., Liang, W., Huang, K.X., Li, Q.Y., Sun, Q.Z., Fu, Q., Zhang, S., 2012b. Petrogenesis and Geological Implications of the Oligocene Chongmuda-Mingze Adakite-Like Intrusions and Their Mafic Enclaves, Southern Tibet. J. Geol. 120, 647-669. https://doi.org/10.1086/667812.

Zheng, Y.Y., Zhang, G.Y., Xu, R.K., Gao, S.B., Pang, Y.C., Cao, L., Du, A.D., Shi, Y.R., 2007. Geochronologic constraints on magmatic intrusions and mineralization of the Zhunuo porphyry copper deposit in Gangdese, Tibet. Chin. Sci. Bull. 52, 3139-3147. https://doi.org/10.1007/s11434-007-0406-7.

Zhou, S., 2002. Study on the geochronology of pivotal regions of Gangdese magmatic and Yarlung Zangbo ophiolite belts, Tibet. Ph. D Dissertation, China University of Geosciences, Beijing (in Chinese, with English abstract).

Zhou, S., Mo, X., Zhao, Z., Qiu, R., Niu, Y., Guo, T., and Zhang, S., 2010, 40Ar/39Ar geochronology of post-collisional volcanism in the middle Gangdese belt, southern Tibet. J. Asian Earth Sci., 37, 246-258.

Zhu, G.H., Liang, X.F., Tian, X.B., Yang, H.F., Wu, C.L., Duan, Y.H., Li, W., Zhou, B.B., 2017. Analysis of the seismicity in central Tibet based on the SANDWICH network and its tectonic implications. Tectonophysics 702, 1-7. https://doi.org/10.1016/j.tecto.2017.02.020.