**The Cenozoic multiple-stage uplift of the Qiangtang Terrane, Tibetan Plateau**

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Supplementary material for this paper includes analytical methods, Fig. S1-S3 and Table S1-S4.

**Methods**

Apatite crystals were extracted by standard mineral separation techniques followed by handpicking. AFT and AHe analyses were conducted at the University of Melbourne and results are shown in Figure 3 and Table S1-S3. Details of low temperature thermochronology analytical procedures are described below.

**Apatite Fission Track (AFT) Thermochronology**

After apatite grains picked by standard heavy liquid and magnetic separation process, they were mounted in epoxy resin on glass slides, ground and polished to expose internal grain surfaces. Polished mounts were etched to reveal fossil tracks, and applied an aluminium/gold coating to reduce reflections from grain boundaries under the microscope (Gleadow et al., 2009). Then the homogeneous track distributions were selected using a Zeiss Axio Imager M1m microscope. Analyses were performed on image sets captured by TrackWorks using a 3.2 MP AVT Oscar F-320C camera mounted on a Zeiss AxioImager microscope with a 1000x total magnification and a 100x dry objective (calibration = 0.07/0.07µm/pixel). Spontaneous track densities were measured on prismatic internal apatite surfaces after etching with 5M HNO3 for 20sec at 20ºC. Track counts were obtained by automated counting in FastTracks using the 'coincidence mapping' technique of Gleadow et al. (2009) followed by manual inspection. Uranium concentrations of each grain were determined by LA-ICP-MS single spot analysis using a New Wave Nd:YAG Laser (λ=213nm with 5Hz, spot size=25μm) connected to an Agilent 7700 mass spectrometer. NIST612 was used as an internal LA-ICP-MS standard. Single grain and pooled ages were calculated according to Hasebe et al. (2004). Central ages were estimated from single grain ages and errors according to the formulas given by Galbraith (2005, p.100) using the Newton-Raphson method. All ages are "model" ages obtained using a range factor (Rs) of 7.17μm (average mean track length of Durango and Fish Canyon Tuff standards) and are directly comparable to conventional External Detector Method ages. Confined track lengths (TINTs) were measured as true 3D lengths using FastTracks after irradiation by 252Cf and are corrected for a refractive index of 1.634 for apatite.

**Apatite U-Th/He Thermochronology**

For U-Th/He analysis, inclusion-free apatite and zircon grains were hand-picked after examination under a binocular microscope. Ages were corrected for alpha ejection (Farley et al., 1996). He extraction was performed using fixed laboratory routines (e.g., House et al., 2002). Apatite grains were loaded into platinum capsules and outgassed under vacuum by using a fibre-optically coupled diode laser. 4He abundances were determined as an isotope ratio using a pure 3He spike that has been calibrated against an independent 4He standard. The uncertainty in the 4He measurement is set as <1%. Apatite U-Th-Sm dating was used an Agilent 7700 quadrupole ICP-MS. The same spike amounts were treated equivalently as unspiked reagent blanks. Another bombing in HCl ensured dissolution of fluoride salts and analysis on an Agilent 7700 quadrupole ICP-MS. Analytical uncertainties for the University of Melbourne U-Th/He equipment are estimated at ~6.2% (± 1σ), which include an α-correction related component and in view of an estimated 5 μm uncertainty in grain size measurements, gas analysis and instrumental error. Durango apatite was measured as internal standards and used as an additional monitor for analytical precision.

**Figure S1.** Inverse HeFTy thermal history modeling results of sample R and RGL series. Etch pit diameters (Dpar) of all analysed grains (age/length) were determined and illustrated.

**Figure S2.** Inverse HeFTy thermal history modeling results of sample G and CBG series. Etch pit diameters (Dpar) of all analysed grains (age/length) were determined and illustrated.

**Figure S3.** Locations of collected and our new thermochronology ages and profiles for Figure 5.

**Table S1.** Sample information.

**Table S2.** Results of apatite (U-Th-Sm)/He dating.

**Table S3.** Results of apatite fission track dating.

**Table S4.** Our new and collected thermochronology ages.

**Table S1,** Sample information.

|  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- |
| **Sample ID** | **Sample Number** | **Lithology** | **Latitude** | **Longitude** | **Elevation** | **AFT** | **AHe** | **Protolith**  **age** |
| **(°E)** | **(°N)** | **(m)** |  |  |
| **1** | G-1 | Granite | 33.342 | 88.407 | 5313 | √ | √ | Late Triassic |
| **2** | G-3 | Granite | 33.340 | 88.406 | 5232 | √ | √ |
| **3** | G-5 | Granite | 33.338 | 88.403 | 5073 | √ | √ |
| **4** | G-7 | Granite | 33.321 | 88.428 | 4900 | √ | √ |
| **5** | G-11 | Granite | 33.264 | 88.371 | 4839 | √ | √ |
| **6** | G-13 | Granite | 33.266 | 88.146 | 4920 | √ | √ |
| **7** | R-1 | Granite | 33.186 | 86.617 | 5802 | √ | √ | ~210 Ma |
| **8** | R-3 | Granite | 33.191 | 86.619 | 5648 | √ | √ |
| **9** | R-5 | Granite | 33.191 | 86.623 | 5461 | √ | √ |
| **10** | R-7 | Granite | 33.191 | 86.628 | 5258 | √ | √ |
| **11** | R-10 | Granite | 33.179 | 86.642 | 4922 | √ | √ |
| **12** | RGL-1 | Granite | 33.202 | 86.381 |  | √ | √ | Late Triassic |
| **13** | RGL-2 | Granite | 33.197 | 86.371 |  | √ | √ |
| **14** | CBG-1 | Granite | 33.723 | 83.678 | 5720 | √ | √ | Jurassic |
| **15** | CBG-5 | Granite | 33.729 | 83.668 | 5551 | √ | √ |
| **16** | CBG-7 | Granite | 33.717 | 83.667 | 5458 |  | √ |
| **17** | CBG-9 | Granite | 33.740 | 83.669 | 5316 | √ | √ |
| **18** | CBG-13 | Granite | 33.690 | 83.805 | 4894 |  | √ |

**Table S2,** Results of apatite (U-Th-Sm)/He dating.

|  |  |  |  |  |  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
| **Sample number** | **4He gas**  **(ncc)** | **Mass**  **(mg)** | **aMean**  **FT** | **U**  **(ppm)** | **Th**  **(ppm)** | **Sm**  **(ppm)** | **Th/U** | **b[eU]**  **(ppm)** | **Corrected Age**  **(Ma)** | **Error ±1s**  **(Ma)** | **Grain length**  **(mm)** | **Grain half-width (mm)** | **Agec**  **(Ma±1σ)** |
| G-1d | 1.930 | 0.0079 | 0.76 | 16.0 | 35.4 | 162.7 | 2.22 | 24.3 | **106.8** | **6.6** | 239.0 | 63.1 | 64**±**12 |
| G-1 | 1.701 | 0.0057 | 0.76 | 26.6 | 65.3 | 253.5 | 2.46 | 41.9 | **76.1** | **4.7** | 254.8 | 56.4 |
| G-1 | 0.421 | 0.0046 | 0.71 | 13.1 | 29.7 | 137.9 | 2.26 | 20.1 | **52.2** | **3.2** | 206.8 | 51.6 |
| G-3 | 1.863 | 0.0084 | 0.75 | 19.4 | 49.8 | 172.8 | 2.57 | 31.1 | **77.1** | **4.8** | 293.9 | 58.5 | 63**±**6.7 |
| G-3 | 0.547 | 0.0055 | 0.72 | 13.2 | 29.8 | 117.0 | 2.26 | 20.2 | **55.1** | **3.4** | 236.6 | 53.0 |
| G-3 | 0.868 | 0.0074 | 0.75 | 14.4 | 29.5 | 145.6 | 2.04 | 21.3 | **59.4** | **3.7** | 252.2 | 59.3 |
| G-5 | 0.900 | 0.0060 | 0.73 | 15.9 | 42.2 | 153.9 | 2.66 | 25.8 | **64.6** | **4.0** | 254.8 | 53.4 | 55**±** 4.7 |
| G-5 | 0.455 | 0.0037 | 0.69 | 17.5 | 46.0 | 166.7 | 2.62 | 28.3 | **51.0** | **3.2** | 192.4 | 48.2 |
| G-5 | 0.540 | 0.0057 | 0.73 | 13.4 | 33.3 | 141.8 | 2.49 | 21.2 | **50.3** | **3.1** | 240.0 | 53.3 |
| G-7 | 1.248 | 0.0081 | 0.77 | 14.6 | 40.0 | 173.9 | 2.73 | 24.0 | **68.2** | **4.2** | 224.2 | 65.8 | 71**±**2.8 |
| G-7d | 1.908 | 0.0066 | 0.75 | 20.1 | 58.2 | 131.8 | 2.90 | 33.8 | **92.2** | **5.7** | 197.4 | 63.6 |
| G-7 | 1.261 | 0.0076 | 0.77 | 14.8 | 37.8 | 159.9 | 2.55 | 23.7 | **73.8** | **4.6** | 202.0 | 67.5 |
| G-11 | 0.476 | 0.0052 | 0.71 | 10.9 | 42.7 | 123.0 | 3.92 | 20.9 | **49.7** | **3.1** | 249.7 | 50.3 | 56**±** 3.7 |
| G-11 | 0.907 | 0.0058 | 0.72 | 15.9 | 65.6 | 143.4 | 4.14 | 31.3 | **56.3** | **3.5** | 254.7 | 52.5 |
| G-11 | 0.982 | 0.0076 | 0.75 | 10.2 | 51.6 | 178.6 | 5.05 | 22.3 | **62.6** | **3.9** | 269.5 | 58.4 |
| G-13 | 1.557 | 0.0072 | 0.75 | 18.8 | 50.1 | 145.9 | 2.66 | 30.6 | **76.0** | **4.7** | 225.1 | 62.1 | 76**±**0.6 |
| G-13 | 1.065 | 0.0103 | 0.76 | 9.2 | 22.2 | 146.3 | 2.41 | 14.4 | **76.1** | **4.7** | 371.8 | 57.7 |
| G-13 | 2.158 | 0.0121 | 0.81 | 14.3 | 37.2 | 119.9 | 2.60 | 23.0 | **77.7** | **4.8** | 236.5 | 71.4 |
| R-1 | 7.925 | 0.0231 | 0.85 | 20.8 | 11.4 | 215.5 | 0.55 | 23.5 | **138.6** | **8.6** | 347.2 | 81.4 | 123**±**7.8 |
| R-1 | 9.392 | 0.0222 | 0.84 | 29.7 | 27.0 | 275.2 | 0.91 | 36.0 | **113.0** | **7.0** | 367.2 | 77.5 |
| R-1 | 1.934 | 0.0078 | 0.77 | 19.9 | 9.0 | 196.8 | 0.45 | 22.0 | **118.7** | **7.4** | 326.1 | 48.7 |
| R-3d | 10.767 | 0.0112 | 0.81 | 33.2 | 12.6 | 226.7 | 0.38 | 36.2 | **262.7** | **16.3** | 285.0 | 62.6 | 134**±**8.3 |
| R-3 | 2.989 | 0.0069 | 0.76 | 30.9 | 14.2 | 265.2 | 0.46 | 34.2 | **134.1** | **8.3** | 289.2 | 48.8 |
| R-3d | 2.285 | 0.0045 | 0.71 | 27.1 | 16.3 | 285.6 | 0.60 | 30.9 | **186.3** | **11.6** | 344.3 | 41.3 |
| R-5 | 4.984 | 0.0181 | 0.84 | 27.3 | 10.8 | 206.4 | 0.39 | 29.8 | **89.4** | **5.5** | 314.2 | 75.6 | 81**±**4.8 |
| R-5 | 7.312 | 0.0220 | 0.85 | 40.7 | 13.2 | 207.7 | 0.32 | 43.8 | **72.9** | **4.5** | 356.0 | 78.4 |
| R-5 | 3.602 | 0.0079 | 0.79 | 50.9 | 28.1 | 240.9 | 0.55 | 57.5 | **81.8** | **5.1** | 216.9 | 60.2 |
| R-7 | 1.288 | 0.0066 | 0.76 | 19.9 | 14.4 | 240.6 | 0.73 | 23.3 | **89.1** | **5.5** | 238.5 | 52.4 | 97**±** 7.9 |
| R-7d | 7.476 | 0.0068 | 0.76 | 30.9 | 13.0 | 259.4 | 0.42 | 34.0 | **341.6** | **21.2** | 356.5 | 50.1 |
| R-7 | 1.224 | 0.0046 | 0.73 | 24.2 | 16.1 | 238.1 | 0.67 | 28.0 | **104.9** | **6.5** | 228.3 | 44.9 |
| R-10d | 5.987 | 0.0064 | 0.77 | 35.3 | 21.1 | 291.9 | 0.60 | 40.3 | **242.2** | **15.0** | 289.9 | 55.2 |  |
| R-10d | 6.035 | 0.0066 | 0.76 | 47.4 | 45.8 | 295.6 | 0.97 | 58.2 | **166.8** | **10.3** | 302.3 | 54.6 |
| R-10d | 9.483 | 0.0081 | 0.77 | 30.2 | 25.3 | 297.4 | 0.84 | 36.1 | **333.2** | **20.7** | 363.6 | 54.6 |
| RGL-1 | 3.637 | 0.0149 | 0.82 | 28.9 | 112.3 | 107.3 | 3.88 | 55.3 | **43.9** | **2.7** | 146.2 | 100.8 | 39**±**4.1 |
| RGL-1 | 1.898 | 0.0194 | 0.83 | 10.9 | 68.0 | 121.7 | 6.23 | 26.9 | **35.6** | **2.2** | 227.4 | 92.0 |
| RGL-1d | 5.834 | 0.0106 | 0.82 | 40.7 | 8.9 | 254.9 | 0.22 | 42.8 | **127.8** | **7.9** | 199.0 | 72.6 |
| RGL-2d | 5.523 | 0.0072 | 0.79 | 46.1 | 11.7 | 204.9 | 0.25 | 48.8 | **160.9** | **10.0** | 209.2 | 58.6 | 100**±**6.3 |
| RGL-2d | 13.386 | 0.0066 | 0.80 | 58.6 | 18.9 | 252.6 | 0.32 | 63.0 | **321.7** | **19.9** | 199.1 | 72.3 |
| RGL-2 | 8.062 | 0.0118 | 0.85 | 63.1 | 6.2 | 320.5 | 0.10 | 64.6 | **100.9** | **6.3** | 213.7 | 97.8 |
| CBG-1 | 1.274 | 0.0063 | 0.75 | 17.8 | 61.3 | 47.8 | 3.45 | 32.2 | **68.3** | **4.2** | 199.2 | 56.0 | 65**±**1.5 |
| CBG-1 | 1.643 | 0.0083 | 0.75 | 18.7 | 65.5 | 47.6 | 3.51 | 34.1 | **63.0** | **3.9** | 294.5 | 58.3 |
| CBG-1 | 1.178 | 0.0062 | 0.72 | 17.2 | 65.1 | 61.7 | 3.78 | 32.5 | **65.5** | **4.1** | 311.0 | 44.7 |
| CBG-5 | 7.452 | 0.0295 | 0.86 | 19.9 | 71.8 | 65.0 | 3.61 | 36.8 | **65.2** | **4.0** | 415.1 | 101.1 | 59**±**3.5 |
| CBG-5 | 1.712 | 0.0119 | 0.79 | 15.6 | 53.3 | 39.4 | 3.43 | 28.1 | **53.1** | **3.3** | 322.9 | 60.5 |
| CBG-5 | 1.515 | 0.0112 | 0.79 | 13.9 | 39.4 | 32.3 | 2.83 | 23.2 | **60.7** | **3.8** | 315.4 | 59.4 |
| CBG-7 | 2.097 | 0.0080 | 0.80 | 25.4 | 84.3 | 65.7 | 3.31 | 45.2 | **59.6** | **3.7** | 221.6 | 74.7 | 60**±**3.6 |
| CBG-7 | 4.830 | 0.0119 | 0.82 | 42.9 | 74.1 | 52.7 | 1.73 | 60.3 | **67.3** | **4.2** | 280.5 | 79.2 |
| CBG-7 | 2.788 | 0.0111 | 0.80 | 29.6 | 71.9 | 55.7 | 2.43 | 46.5 | **54.9** | **3.4** | 317.9 | 70.2 |
| CBG-9 | 1.901 | 0.0076 | 0.76 | 28.6 | 41.6 | 95.3 | 1.45 | 38.4 | **69.9** | **4.3** | 234.6 | 62.3 | 52**±**9.2 |
| CBG-9 | 3.047 | 0.0081 | 0.76 | 56.3 | 100.9 | 138.8 | 1.79 | 80.0 | **50.1** | **3.1** | 257.2 | 61.7 |
| CBG-9 | 1.839 | 0.0160 | 0.83 | 22.2 | 30.9 | 75.0 | 1.39 | 29.5 | **38.5** | **2.4** | 254.5 | 79.1 |
| CBG-13d | 3.662 | 0.0140 | 0.81 | 55.2 | 156.1 | 96.4 | 2.83 | 91.9 | **28.7** | **1.8** | 372.2 | 72.1 | 57**±**12.6 |
| CBG-13 | 0.871 | 0.0046 | 0.73 | 16.1 | 60.5 | 60.2 | 3.76 | 30.3 | **70.0** | **4.3** | 134.5 | 58.1 |
| CBG-13 | 0.515 | 0.0065 | 0.77 | 10.3 | 35.8 | 55.8 | 3.48 | 18.7 | **44.9** | **2.8** | 149.0 | 66.1 |

**Note:**

aFT is the -ejection correction after Wolf et al. (1996).

bEffective uranium concentration (U ppm + 0.235 × Th ppm) (Flowers et al., 2009).

cAge = Average age ± standard deviation.

dExcluded in the calculation of average age.

**Table S3,** Results of apatite fission track dating.

|  |  |  |  |  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
| **Sample ID** | **Sample number** | **No. of**  **Grains** | **Ns** | **ρs**  **(105cm-2)** | **Mean 238U and SD**  **(ppm)** | **P(χ2)**  **(%)** | **Dpar**  **(μm)** | **Pooled Age**  **(Ma±1σ)** | **Central Age**  **(Ma±1σ)** | **Non-projected**  **Mean track length** | **Projected**  **Mean track length** | **Nlength** |
| 1 | G-1 | 21 | 1791 | 12.0122 | 24.21 ± 5.34 | 40 | 1.67 | 101±3.7 | 104±3.3 | 13.27 ± 1.94 | 14.30 ± 1.38 | 128 |
| 2 | G-3 | 22 | 2196 | 11.5052 | 21.89 ± 5.45 | 39 | 2.10 | 108±3.6 | 111±3.3 | 12.6 ± 2.26 | 13.82 ± 1.51 | 139 |
| 3 | G-5 | 26 | 1703 | 10.0655 | 16.43 ± 3.30 | 85 | 2.14 | 126±3.8 | 127±4.4 | 12.98 ± 1.72 | 14.01 ± 1.23 | 118 |
| 4 | G-7 | 25 | 1952 | 10.8023 | 18.24 ± 4.42 | 71 | 2.24 | 123±3.5 | 125±3.9 | 12.05 ± 2.00 | 13.48 ± 1.34 | 106 |
| 5 | G-11 | 24 | 1844 | 10.1140 | 18.55 ± 4.32 | 57 | 2.00 | 114±3.3 | 115±3.5 | 13.32 ± 1.54 | 14.22 ± 1.22 | 126 |
| 6 | G-13 | 25 | 1778 | 9.6064 | 17.85 ± 5.05 | 39 | 1.70 | 115±3.9 | 116±3.6 | 12.22 ± 1.69 | 13.51 ± 1.19 | 124 |
| 7 | R-1 | 25 | 2509 | 14.9686 | 29.13 ± 5.07 | 7 | 1.53 | 106±3.8 | 106±3.6 | 12.35 ± 1.53 | 13.52 ± 1.17 | 124 |
| 8 | R-3 | 21 | 2727 | 17.8731 | 32.9 ± 7.49 | 24 | 1.52 | 116±3.7 | 117±3.6 | 12.55 ± 1.66 | 13.70 ± 1.20 | 155 |
| 9 | R-5 | 23 | 2843 | 13.1788 | 31.57 ± 9.79 | 44 | 1.43 | 88±2.8 | 89±2.6 | 11.82 ± 1.99 | 13.32 ± 1.27 | 117 |
| 10 | R-7 | 24 | 2040 | 9.9168 | 28.41 ± 7.48 | 48 | 1.47 | 74±2.4 | 75±2.4 | 12.36 ± 1.62 | 13.53 ± 1.17 | 114 |
| 11 | R-10 | 22 | 1984 | 14.8425 | 29.83 ± 8.09 | 53 | 1.31 | 105±3.2 | 105±3.3 | 12.31 ± 1.66 | 13.55 ± 1.20 | 137 |
| 12 | RGL-1 | 25 | 3989 | 17.2432 | 48.11 ± 15.13 | 69 | 1.43 | 75±1.8 | 75±1.9 | 12.15 ± 1.67 | 13.44 ± 1.17 | 146 |
| 13 | RGL-2 | 30 | 5617 | 17.5187 | 88.44 ± 73.03 | 0 | 1.65 | 42±9.7 | 55±7.8 | 12.91 ± 1.58 | 13.91 ± 1.15 | 141 |
| 14 | CBG-1 | 21 | 2786 | 11.4079 | 18.82 ± 3.68 | 61 | 1.70 | 126±3.5 | 125±3.5 | 12.82 ± 1.42 | 13.86 ± 1.00 | 141 |
| 15 | CBG-5 | 23 | 3787 | 10.8439 | 22.72 ± 7.93 | 8 | 1.63 | 98±4.2 | 100±4.0 | 12.76 ± 1.67 | 13.88 ± 1.23 | 119 |
| 16 | CBG-9 | 20 | 3244 | 15.1972 | 24.79 ± 12.26 | 50 | 1.54 | 130±3.7 | 132±3.6 | 12.67 ± 1.87 | 13.84 ± 1.28 | 170 |

**Note:** Ns = number of spontaneous tracks counted; ρs = spontaneous track density; Dpar = long axis of track etch pit. P(χ2) = chi-squared probability that all single-crystal ages represent a single population of ages where degrees of freedom =N-1(Galbraith, 1981). Non-projected Track length measured after 252Cf irradiation. c axis projected mean track length after Ketcham et al. (2007). Nlength = number of lengths measured. P(χ2) measured by using the RadialPlotter. (Vermeesch, 2009). Fission track age is pooled age if P(χ2)>5%, is central age if P(χ2) <5% (Galbraith and Green, 1990). The apatite fission track (AFT) ages measured in samples RGL-2 (Table S3) do not pass the standard χ2 criterion (Galbraith, 1981; Green, 1981), suggesting that single-grain AFT ages are not derived from the same population.

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