

*Tectonics*

Supporting Information for

**Heterogeneous exhumation of the Mount Isa orogen in NE Australia after 1.6 Ga Nuna assembly: new high-precision 40Ar/39Ar thermochronological constraints**

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| **Table S1.** Previously published 40Ar/39Ar thermochronology results from the Mount Isa Inlier. | | | | | | | | | |
|
| Sample ID | Mineral | Lithology | Domain | Age (Ma) | Plateau age | Reference | Latitude | Longitude | Age interpretation |
| 93-1178 | Hornblende | Ore, Kuridala Group, Osborne Deposit | Kuridala-Selwyn Domain | 1530±2 | Mini | Perkins & Wyborn 1998 | -22.081503 | 140.584169 | Mineralization |
| 93-1175 | Hornblende | Ore, Kuridala Group, Osborne Deposit | Kuridala-Selwyn Domain | 1564±2 | Mini | Perkins & Wyborn 1998 | -22.081503 | 140.584169 | Alteration or mineralization |
| 93-1250 | Actinolite | Ore, Mt. Elliott Deposit | Kuridala-Selwyn Domain | 1396±4 | No Plateau | Perkins & Wyborn 1998 | N/A | N/A | Fluid |
| 93-1479 | Hornblende | Ore, Ernest Henry Deposit | Kuridala-Selwyn Domain | 1490±1 | No Plateau | Perkins & Wyborn 1998 | N/A | N/A | Alteration or mineralization |
| 94-244 | Hornblende | Ore, Mt. Elliott Deposit | Kuridala-Selwyn Domain | 1431±2 | No Plateau | Perkins & Wyborn 1998 | N/A | N/A | Alteration or mineralization |
| 94-243 | Hornblende | Ore, Mt. Elliott Deposit | Kuridala-Selwyn Domain | 1513±2 | Mini | Perkins & Wyborn 1998 | N/A | N/A | Alteration or mineralization |
| 93-1238 | Muscovite | Altered William Granite Suite | Kuridala-Selwyn Domain | 1439±4 | Mini | Perkins & Wyborn 1998 | N/A | N/A | Alteration |
| 94-289 | Muscovite | Ore, Maronan Deposit | Kuridala-Selwyn Domain | 1481±1 | No Plateau | Perkins & Wyborn 1998 | N/A | N/A | Alteration or mineralization |
| 94-280 | Muscovite | Ore, Mt. Elliott Deposit | Kuridala-Selwyn Domain | 1512±2 | Mini | Perkins & Wyborn 1998 | N/A | N/A | Alteration or mineralization |
| 93-1294 | Biotite | Ore, Osborne Deposit | Kuridala-Selwyn Domain | 1476±1 | Yes | Perkins & Wyborn 1998 | N/A | N/A | Alteration or mineralization |
| 93-1253 | Biotite | Ore, Mt. Elliott Deposit | Kuridala-Selwyn Domain | 1447±2 | No Plateau | Perkins & Wyborn 1998 | N/A | N/A | Alteration or mineralization |
| 93-1481 | Biotite | Ore, Ernest Henry Deposit | Kuridala-Selwyn Domain | 1461±2 | No Plateau | Perkins & Wyborn 1998 | N/A | N/A | Alteration or mineralization |
| 93-1189 | Biotite | Ore, Ernest Henry Deposit | Kuridala-Selwyn Domain | 1100±9 | No Plateau | Perkins & Wyborn 1998 | N/A | N/A | Alteration or mineralization |
| 93-1481 | Biotite | William Suit, Ernest Henry Deposit | Kuridala-Selwyn Domain | 1478±16 | Mini | Perkins & Wyborn 1998 | -22.081503 | 140.584169 | Alteration or mineralization |
| 93-1486 | Biotite | Ore, Ernest Henry Deposit | Kuridala-Selwyn Domain | 1483±1 | No Plateau | Perkins & Wyborn 1998 | N/A | N/A | Alteration or mineralization |
| 94-243 | Biotite | Ore, Mt. Elliott Deposit | Kuridala-Selwyn Domain | 1505±2 | Mini | Perkins & Wyborn 1998 | N/A | N/A | Alteration or mineralization |
| 94-230 | Biotite | Ore, Mt. Elliott Deposit | Kuridala-Selwyn Domain | 1540±2 | Mini | Perkins & Wyborn 1998 | N/A | N/A | Alteration or mineralization |
| 93-1230 | Hornblende | Alpha Centauri Metamorphics | Sybella Domain | 1457±3 | No Plateau | Perkins 1999 | -20.819228 | 139.439606 | Fault activity |
| 93-1221 | Muscovite | Urquhart Shale, Holley Fault | Leichardt River Domain | 1367±1 | Mini | Perkins 1999 | -20.724522 | 139.478164 | Fault activity |
| 93-1185 | sericite | Buck Quartz Fault | Leichardt River Domain | 1261±1 | No Plateau | Perkins 1999 | N/A | N/A | Alteration or mineralization |
| 93-1231 | Muscovite | Chlorite-Muscovite metasomatic zone | Sybella Domain | 1394±1 | Mini | Perkins 1999 | -20.824683 | 139.443392 | Cooling |
| 93-1212 | Biotite | Orebody | Leichardt River Domain | 1526±1 | Mini | Perkins 1999 | N/A | N/A | Mineralization |
| 93-1184 | Biotite | Ore | Sybella Domain | 1523±1 | Mini | Perkins 1999 | N/A | N/A | Alteration or mineralization |
| 93-1229 | Muscovite | Ore | Sybella Domain | 1496±2 | No Plateau | Perkins 1999 | N/A | N/A | Alteration or mineralization |
| 93-1203 | Biotite | Altered Vein | Sybella Domain | 1506±1 | Mini | Perkins 1999 | N/A | N/A | Alteration or mineralization |
| 93-1181 | Biotite | Eastern Creek Volcanics | Sybella Domain | 1320±1 | No Plateau | Perkins 1999 | N/A | N/A | Alteration or mineralization |
| 93-1208 | Biotite | Altered Basalt | Leichardt River Fault Domain | 1515±1 | No Plateau | Perkins 1999 | N/A | N/A | Alteration or mineralization |
| AG6126 | Hornblende | Squirrel Hills Granite, William | Kuridala-Selwyn Domain | 1455±2 | Yes | Spikings et al., 2001 | -21.728611 | 140.846389 | Cooling |
| TC3 | Hornblende | Rhyolite, Corella Formation | Tommy Creek Domain | 1398±5 | No Plateau | Spikings et al., 2001 | -20.761944 | 140.178889 | Cooling |
| TC5 | Hornblende | Dolerite, | Tommy Creek Domain | 1457±5 | No Plateau | Spikings et al., 2001 | -20.748889 | 140.165 | Cooling |
| AG6111 | Hornblende | Wimberu Granite | Mitakoodi Domain | 1456±2 | No Plateau | Spikings et al., 2001 | -21.309167 | 140.348333 | Cooling |
| AG8038 | Hornblende | Mount Margaret Granite, Naraku | Kuridala-Selwyn Domain | 1493±8 | No Plateau | Spikings et al., 2001 | -20.458056 | 140.815833 | Cooling |
| AG8029 | Hornblende | Rhyolite, Mount Fort Constantine Volcanics | Cloncurry Domain | 1550±5 | No Plateau | Spikings et al., 2001 | -20.488611 | 140.609722 | Cooling |
| AG8076 | Hornblende | Boomarra Metamorphics | Mary Kathleen Domain | 1458±6 | No Plateau | Spikings et al., 2001 | -19.768056 | 140.24 | Cooling |
| AG6133 | Biotite | Gin Creek Granite | Kuridala-Selwyn Domain | 1435±3 | No Plateau | Spikings et al., 2001 | -21.662778 | 140.45 | Cooling |
| KS18 | Muscovite | Schist, Kuridala Group | Kuridala-Selwyn Domain | 1370±6 | No Plateau | Spikings et al., 2001 | -21.698056 | 140.531111 | Cooling |
| KS20 | Muscovite | Schist, New Hope Sandstone | Kuridala-Selwyn Domain | 1400±5 | Mini | Spikings et al., 2001 | -21.701111 | 140.537778 | Cooling |
| MK24 | Muscovite | Quartzite, Overhang Jaspilite | Mitakoodi Domain | 1316±7 | No Plateau | Spikings et al., 2001 | -20.765 | 140.208056 | Cooling |
| MK7 | Muscovite | Limestone, Overhang Jaspilite | Mitakoodi Domain | 1400±5 | No Plateau | Spikings et al., 2001 | -20.786944 | 140.16 | Cooling |
| KS16 | Biotite | Wimberu Granite | Kuridala-Selwyn Domain | 1446±3 | No Plateau | Spikings et al., 2001 | -21.69888889 | 140.53 | Cooling |
| KS17 | Biotite | Wimberu Granite | Kuridala-Selwyn Domain | 1428±8 | No Plateau | Spikings et al., 2001 | -21.698889 | 140.531111 | Cooling |
| AG6133 | Biotite | Gin Creek Granite | Marimo-Staveley Domain | 1576±18 | Mini | Spikings et al., 2001 | -21.662778 | 140.45 | Cooling |
| RS1b | Biotite | Naraku Granite | Kuridala-Selwyn Domain | 1408±5 | Yes | Spikings et al., 2001 | -20.1225 | 140.233611 | Cooling |
| TC4 | Biotite | Milo Bed Schist | Tommy Creek Domain | 1481±5 | No Plateau | Spikings et al., 2001 | -20.753056 | 140.18 | Cooling |
| AG6111 | Biotite | Wimberu Granite | Mitakoodi Domain | 1456±2 | No Plateau | Spikings et al., 2001 | -21.309167 | 140.348333 | Cooling |
| KS19 | Biotite | Schist, Corella Formation | Mary Kathleen Domain | 1405±5 | No Plateau | Spikings et al., 2001 | -21.69694444 | 140.5455556 | Cooling |
| KS20 | Biotite | Schist, New Hope Sandstone | Kuridala-Selwyn Domain | 1400±5 | No Plateau | Spikings et al., 2001 | -21.701111 | 140.537778 | Cooling |
| AG5030 | Biotite | Jessie Granite | Kuridala-Selwyn Domain | 1435±5 | No Plateau | Spikings et al., 2001 | -20.70111111 | 140.4761111 | Cooling |
| RS22 | Biotite | Capsize Granodiorite | Kuridala-Selwyn Domain | 1436±8 | No Plateau | Spikings et al., 2001 | -20.36722222 | 140.2608333 | Cooling |
| 6120 | Hornblende | Kalkadoon Granite | Kalkadoon Domain | 1419±7 | Mini | Spikings et al., 2002 | -21.665556 | 139.776389 | Cooling |
| RS45 | Hornblende | Kurbayia Metamorphic Complex | Kalkadoon Domain | 1489±12 | No Plateau | Spikings et al., 2002 | -20.871667 | 139.569444 | Alteration |
| DF61 | Hornblende | Widgewarra Granite | Sybella Domain | 1378±10 | No Plateau | Spikings et al., 2002 | -20.975 | 139.406389 | Cooling |
| DF63 | Hornblende | Alpha Centauri Metamorphics | Sybella Domain | 1439±5 | No Plateau | Spikings et al., 2002 | -20.968611 | 139.408333 | Cooling |
| DF71 | Hornblende | Kalkadoon Granodiorite | Kalkadoon Domain | 1501±5 | No Plateau | Spikings et al., 2002 | -20.660556 | 139.687222 | Cooling |
| 6052 | Hornblende | Kalkadoon Granodiorite | Kalkadoon Domain | 1483±14 | No Plateau | Spikings et al., 2002 | -20.32 | 139.78 | Cooling |
| DF64 | Muscovite | Myally Subgroup | Sybella Domain | 1363±8 | Mini | Spikings et al., 2002 | -20.927222 | 139.444722 | Cooling |
| DF65 | Muscovite | Queen Elizabeth Granite | Sybella Domain | 1225±7 | Mini | Spikings et al., 2002 | -20.944444 | 139.444722 | Cooling |
| DF75 | Muscovite | Eastern Creek Volcanics | Sybella Domain | 1390±4 | Yes | Spikings et al., 2002 | -20.863056 | 139.461111 | Cooling |
| DF72 | Muscovite | Kalkadoon Granodiorite | Kalkadoon Domain | 1388±7 | No Plateau | Spikings et al., 2002 | -20.554722 | 139.750278 | Cooling |
| 6005 | Biotite | Kalkadoon Granodiorite | Kalkadoon Domain | 1488±2 | No Plateau | Spikings et al., 2002 | -19.75 | 139.96 | Cooling |
| 6052 | Biotite | Kalkadoon Granodiorite | Kalkadoon Domain | 1444±4 | No Plateau | Spikings et al., 2002 | -20.32 | 139.78 | Cooling |
| 6065 | Biotite | Kalkadoon Granodiorite | Leichardt River Fault Domain | 1470±9 | Yes | Spikings et al., 2002 | -20.851389 | 139.75 | Cooling |
| 6137 | Biotite | Leichhardt Volcanics | Leichardt River Fault Domain | 1361±6 | Yes | Spikings et al., 2002 | -21.752222 | 139.563889 | Cooling |
| RS4 | Biotite | Kalkadoon Granodiorite | Kalkadoon Domain | 1456±4 | No Plateau | Spikings et al., 2002 | -19.9925 | 139.54.833 | Cooling |
| RS28 | Biotite | Rhyodacite, Leichhardt volcanics | Kalkadoon Domain | 1426±6 | No Plateau | Spikings et al., 2002 | -20.31111111 | 139.8511111 | Cooling |
| RS46 | Biotite | Kalkadoon Granodiorite | Kalkadoon Domain | 1295±7 | No Plateau | Spikings et al., 2002 | -20.936111 | 139.563889 | Cooling |
| RS49 | Biotite | Kalkadoon Granodiorite | Kalkadoon Domain | 1453±4 | Yes | Spikings et al., 2002 | -21.11333333 | 139.6472222 | Cooling |
| RS52 | Biotite | Kalkadoon Granodiorite | Kalkadoon Domain | 1432±3 | Yes | Spikings et al., 2002 | -21.520556 | 139.674444 | Cooling |
| RS53 | Biotite | Steeles Granite | Sybella Domain | 1372±8 | Yes | Spikings et al., 2002 | -20.67472222 | 139.3405555 | Cooling |
| DF60 | Biotite | Widgewarra Granite, Sybella | Sybella Domain | 1378±10 | No Plateau | Spikings et al., 2002 | -20.975 | 139.406389 | Cooling |
| DF75 | Biotite | Schist, Eastern Creek Volcanics | Leichhardt River Domain | 1122±4 | No Plateau | Spikings et al., 2002 | -20.863056 | 139.461111 | Cooling |
| DF76 | Biotite | Kitty Plain Microgranite | Sybella Domain | 1362±5 | No Plateau | Spikings et al., 2002 | -20.538889 | 139.437222 | Cooling |
| 5078 | Biotite | Big Toby Granite | Sybella Domain | 1361±7 | No Plateau | Spikings et al., 2002 | -20.763889 | 139.196944 | Cooling |
| RS54 | Biotite | Gidyea Granite, Sybella | Sybella Domain | 1377±4 | Yes | Spikings et al., 2002 | -21.19666667 | 139.309444 | Cooling |
| 0257 | Biotite | Gabbro | Mary Kathleen Domain | 1442±20 | No Plateau | Page 1983 | -20.750375 | 140.072272 | Cooling |
| AG5032 | Biotite | Malakoff Granite | Kuridala-Selwyn Domain | 1454±4 | No Plateau | Page & Sun 1998 | -20.57 | 140.456111 | Cooling |
| AG6111 | Hornblende | Wimberu Granite | Kuridala-Selwyn Domain | 1456±2 | No Plateau | Page & Sun 1998 | -21.309167 | 140.348333 | Cooling |

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| **Table S2**. Summary of published geochronological constraints and thermo conditions for the peak metamorphism stage in each tectonic domain. | | | | | |
| Location | Metamorphic zone | Peak metamorphism temperature (°C) | Reference | Peak metamorphism age | Reference |
| Eastern Belt | | | | | |
| Central Snake Creek  Anticline  (Cloncurry Domain) | Staurolite/Andalusite | 580–605 °C | Rubenach, 1997 | 1570–1590 Ma;  1600–1608 Ma | Rubenach, 2008; Pourteau et al., 2018. |
| South Snake Creek Anticline  (Cloncurry Domain) | Sillimanite/K-Feldspar | 675 °C | Foster, 2003 |  |  |
| Middle Creek Anticline  (Cloncurry Domain) | Staurolite/Andalusite | 580–605 °C | Foster and Rubenach, 2006 | 1599±10 Ma; | Hand & Rubatto, 2002 |
| Osborne Mine  (Cloncurry Domain) | Sillimanite/K-feldspar | 678–700 °C | Foster, 2003 | 1595±6 Ma;  1595±6 Ma | Hand & Rubatto, 2002; Gautier et al., 2001 |
| Cannington  (Cloncurry Domain) | Sillimanite/K-Feldspar | 665–690 °C | Foster and Rubenach, 2006 | 1577±5 Ma; | Hand & Rubatto, 2002 |
| Cloncurry Domain | Sillimanite | 600–690 °C | Rubenach, 1997; Foster, 2003; Foster and Rubenach, 2006 | 1570–1600 Ma;  1585–1600 Ma;  1584 Ma | Rubenach et al., 2008; Giles and Nutman, 2002; Page and Sun, 1998 |
| Doherty Domain | Calc-silicate Biotite | 500–520 °C |  |  |  |
| Mitakoodi Domain | Lower Greenschist | 510–530 ° C | Foster and Rubenach, 2006 |  |  |
| Tommy Creek Domain | Amphibolite | 550–600 ° C | Foster and Rubenach, 2006 | 1575–1585 Ma | Hand and Rubatto, 2002 |
| Central Belt | | | | | |
| Mary Kathleen Domain | Andalusite/Sillimanite | 580–640 °C;  596 °C | Reinhardt, 1992; Foster 2003 | 1570 Ma; 1590 Ma; | Hand and Rubatto, 2002; Blenkinsop 2005 |
| Central Kalkadoon Domain | Mid-amphibolite | 570–600 °C | Foster, 2002 |  |  |
| Rifle Creek Domain | Upper amphibolite | 500 °C |  |  |  |
| Western Belt | | | | | |
| Sybella Domain | Lower Sillimanite | 570–600 °C | Rubenach, 1992 | 1575 Ma; 1584±3 Ma | Hand and Rubatto, 2002; Geoscience Australia |

Table S3. Initial inputs to Dodson’s (1973) equation (main text, Equation 1) used to calculate mineral closure temperatures and cooling rates. Abbreviations are: *Q*, activation energy; *D0*, diffusion coefficient; *A*, volume constant; , initial closure temperature value; *A*, geometric factor; *a*, effective diffusion ratio; *dT/dt,* initial cooling rate. Recalibrate samples from previous research are in italic, given at a moderate mineral grain size. Closure temperature values are calculated by Monte Carlo simulation, and reported at ± 2σ. Average closure temperatures estimated for hornblende, muscovite, and biotite are 518 ± 53℃, 405 ± 49 ℃, and 329 ± 57 ℃ respectively.

|  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- |
| Sample name | Mineral | (°C) | (µm) | (kcal/mol) | (cm2/s) |  | (°C/Ma) | *Tc* (°C ± 2σ) |
| Eastern Belt | | | | | | | | |
| AML01 | Hbl | 500 | 250–300 | 64.1 ± 1.7 | 0.024 ­ | 55 | 1.2 | 517 ± 52 |
| AMS01 | Hbl | 500 | 75–150 | 64.1 ± 1.7 | 0.024 ­ | 55 | 1.1 | 526 ± 48 |
| MMB03 | Hbl | 500 | 100–150 | 64.1 ± 1.7 | 0.024 ­ | 55 | 0.4 | 486 ± 54 |
| LCF01 | Ms | 425 | 125–150 | 63 ± 7 | 2.3 | 55 | 1.7 | 397 ± 48 |
| MnMs01 | Ms | 425 | 200–250 | 63 ± 7 | 2.3 | 55 | 0.9 | 410 ± 50 |
| CF05 | Ms | 425 | 150–250 | 63 ± 7 | 2.3 | 55 | 1.7 | 408 ± 50 |
| Central Belt | | | | | | | | |
| LCG01 | Hbl | 500 | 250–300 | 64.1 ± 1.7 | 0.024 ­ | 55 | 4.3 | 524 ± 48 |
| KLB1604 | Hbl | 500 | 150–200 | 64.1 ± 1.7 | 0.024 ­ | 55 | 3.7 | 507 ± 50 |
| MLMB01 | Hbl | 500 | 200–300 | 64.1 ± 1.7 | 0.024 ­ | 55 | 1.6 | 516 ± 52 |
| WG01 | Bi | 310 | 250–300 | 50.5 ± 2.2 | 0.4 | 27 | 3.4 | 328 ± 58 |
| KLB1602 | Bt | 310 | 100–200 | 50.5 ± 2.2 | 0.4 | 27 | 1.45 | 329 ± 56 |
| KG03 | Bt | 310 | 250–300 | 50.5 ± 2.2 | 0.4 | 27 | 4.3 | 329 ± 58 |
| *AG6065* | *Bt* | *310* | *200*–*400* | *50.5 ± 2.2* | *0.4* | *27* | *2.5* | *327 ± 57* |
| *RS49* | *Bt* | *310* |  | *50.5 ± 2.2* | *0.4* | *27* |  |  |
| Western Belt | | | | | | | | |
| SG01 | Hbl | 500 | 300–450 | 64.1 ± 1.7 | 0.024 ­ | 55 | 2 | 532 ± 54 |
| CRS01 | Hbl | 500 | 150–250 | 64.1 ± 1.7 | 0.024 ­ | 55 | 1.5 | 507 ± 52 |
| *DF75* | *Ms* | *425* | *200–400* | *63 ± 7* | *2.3* | *55* | *0.96* | *406 ± 51* |
| *RS54* | *Bt* | *310* | *200–400* | *50.5 ± 2.2* | *0.4* | *27* | *1.45* | *331 ± 59* |

Table S4. Probability distributions and values of variables used in the Monte Carlo simulation. The uncertainty of each random variable used in the Monte Carlo simulation was modelled using either a uniform, triangular or normal probability distribution.

|  |  |  |  |
| --- | --- | --- | --- |
| Variable | Input Probability Distribution | Value (± 2 SD) | Source |
| Hornblende |  |  |  |
|  | Triangular (min, mode, max) | 64.1 ± 1.7 kcal/mol | *Harrison* [1981] |
|  | Triangular (min, mode, max) | 0.024 ­ cm2/s |
| Biotite |  |  |  |
|  | Triangular (min, mode, max) | 50.5 ± 2.2 kcal/mol | *Grove and Harrison* [1996] |
|  | Triangular (min, mode, max) | 0.4 cm2/s |
| Muscovite |  |  |  |
|  | Triangular (min, mode, max) | 63 ± 7 kcal/mol | *Harrison et al*. [2009] |
|  | Triangular (min, mode, max) | 22.3 cm2/s |
| Metamorphic age (Ma) | Normal (mean, σ) | Varies for each mineral | Table S2 |
| Metamorphic temperature (°C) | Uniform (min, max) | Varies for each mineral | Table S2 |
| 40Ar/39Ar cooling age (°C) | Normal (mean, σ) | Varies for each mineral | Table 1 |
| Closure temperature (°C) | Not modelled with a probability distribution | The value of the closure temperature is directly calculated by iterating Equation 1 as part of each trial | |
| Cooling rate (°C/Ma) | Not modelled with a probability distribution | Initially calculated based on metamorphic age, metamorphism temperature, 40Ar/39Ar cooling age and the initial estimate of 40Ar/39Ar closure temperature. The cooling rate is recalculated after every propagation of Equation 1, using the new closure temperature directly calculated as part of each calculation | |

**Table S5.** 40Ar/39Ar analytical data from this study corrected for blank, mass discrimination and radioactive decay.

**Table S6.** K/Ca ration and 40Ar/39Ar normal isochron spectra of the samples dated in this study.

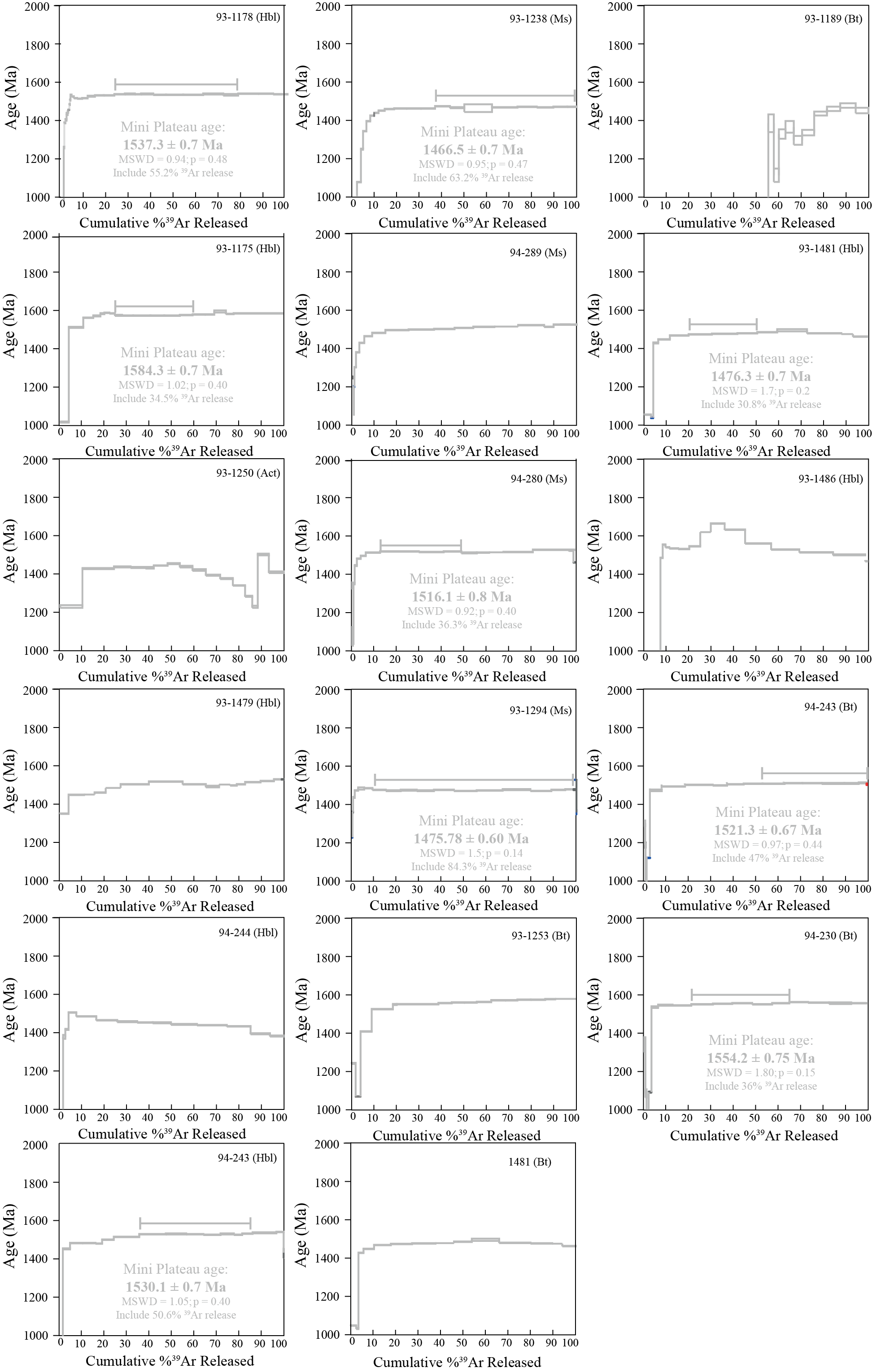
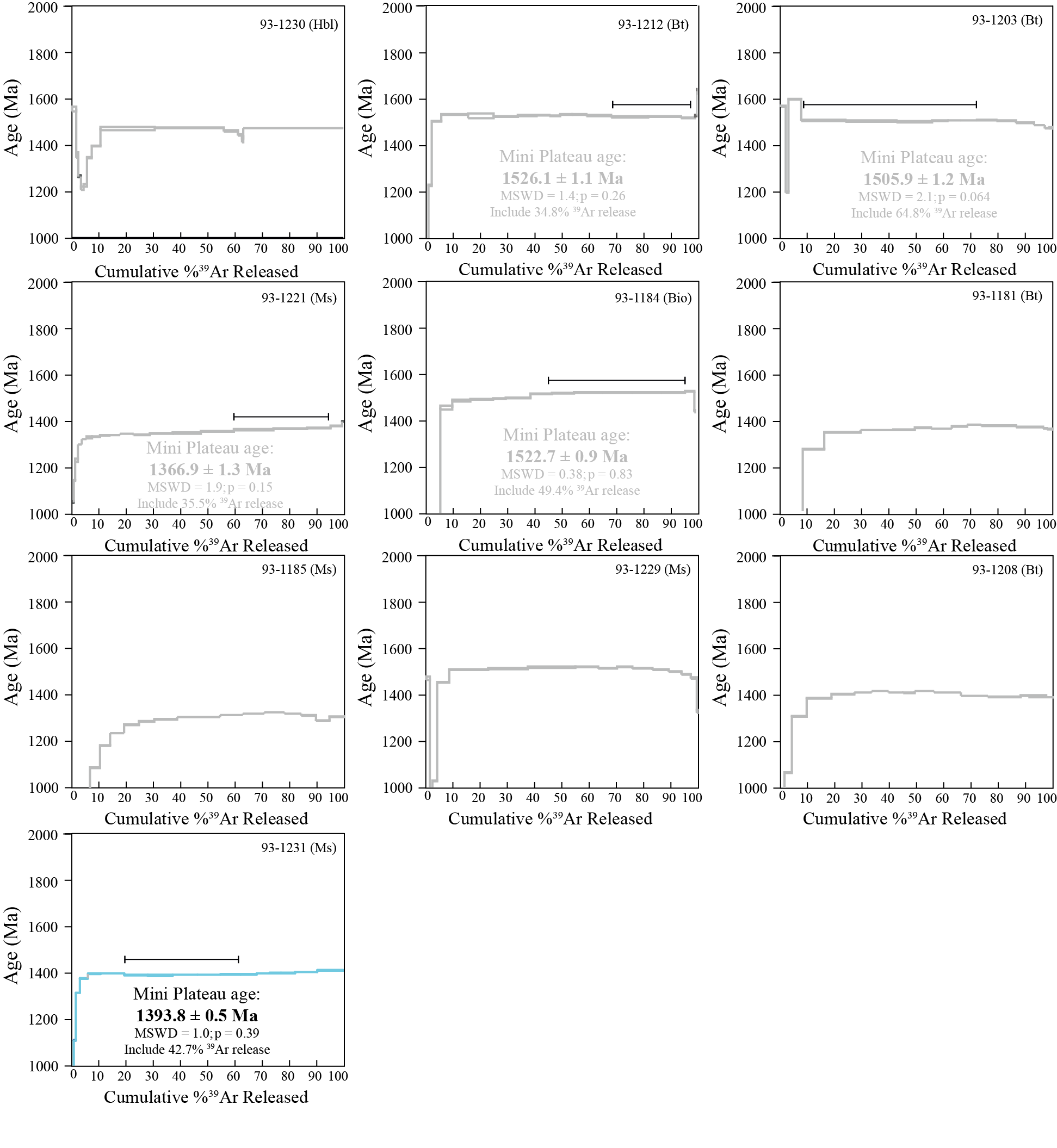
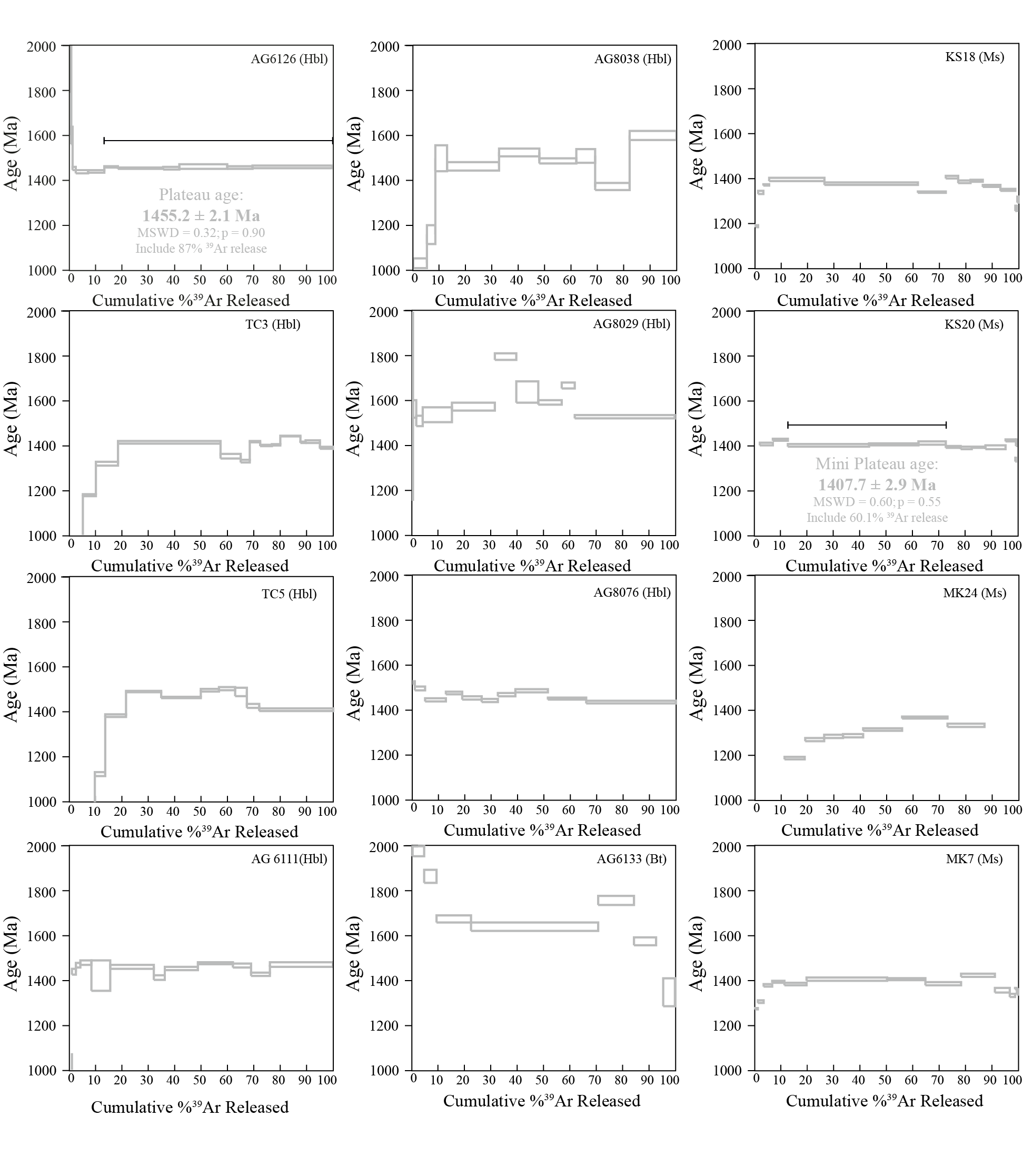


Figure S1. 40Ar/39Ar age spectra recalculatedfrom Perkins and Wyborn [1998] using updated argon decay constant. Spectra with ages in light grey or no quoted ages are the 40Ar/39Ar results discarded in this paper. Whereas those we retained are shown with age plateaus in black (Bt) or blue (Ms). Specific sample information including sample lithology, locations, and stratigraphic positions are listed in Table S1.

**Figure S2.** 40Ar/39Ar age spectra recalculatedfrom Perkins et al. [1999] using updated decay constant. Spectra with ages in light grey or no quoted ages are the 40Ar/39Ar results discarded in this paper. Whereas those we retained are shown with age plateaus in black (Bt) or blue (Ms). Specific sample information including sample lithology, locations, and stratigraphic positions are listed in Table S1**.**



Continue

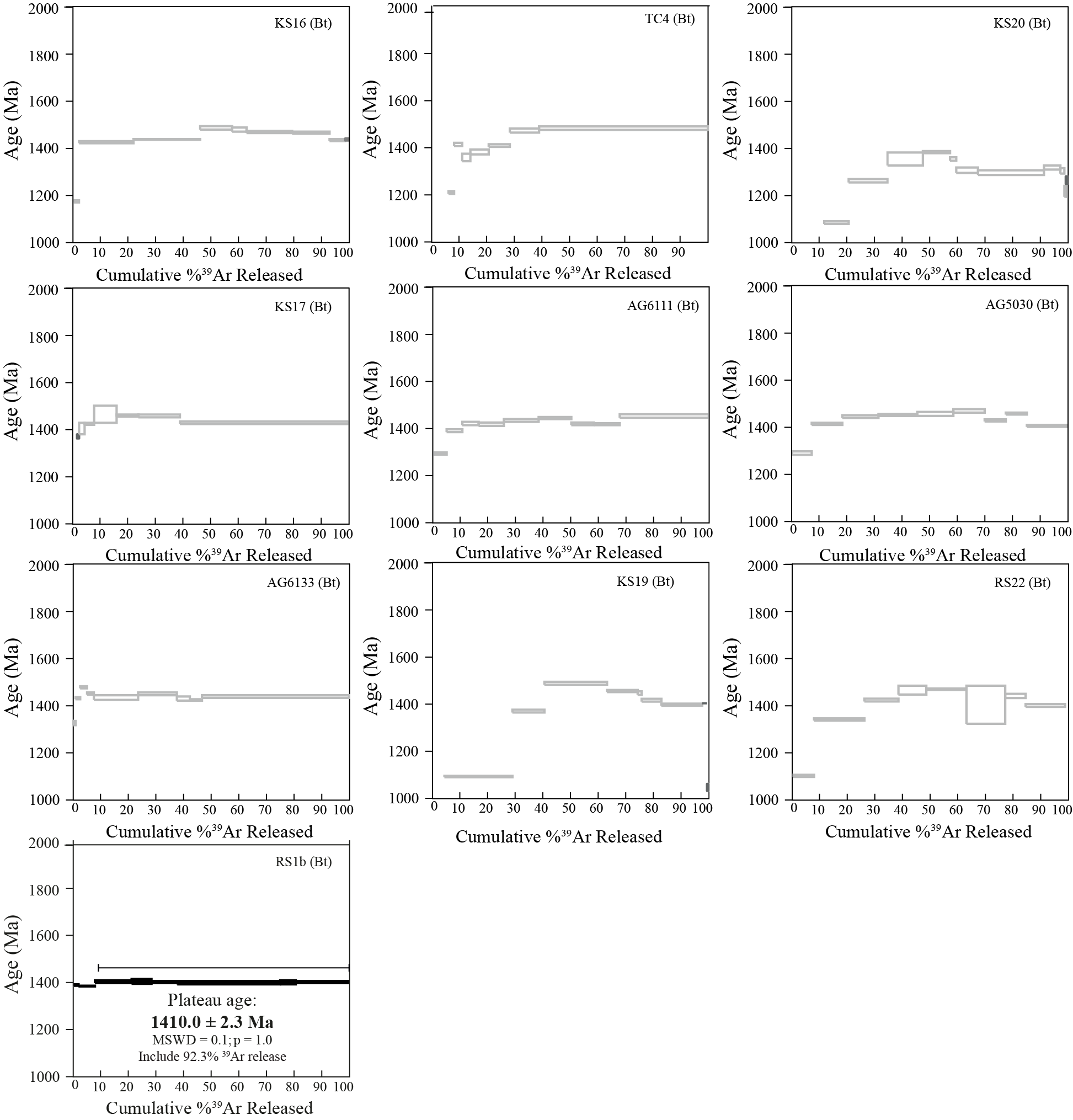
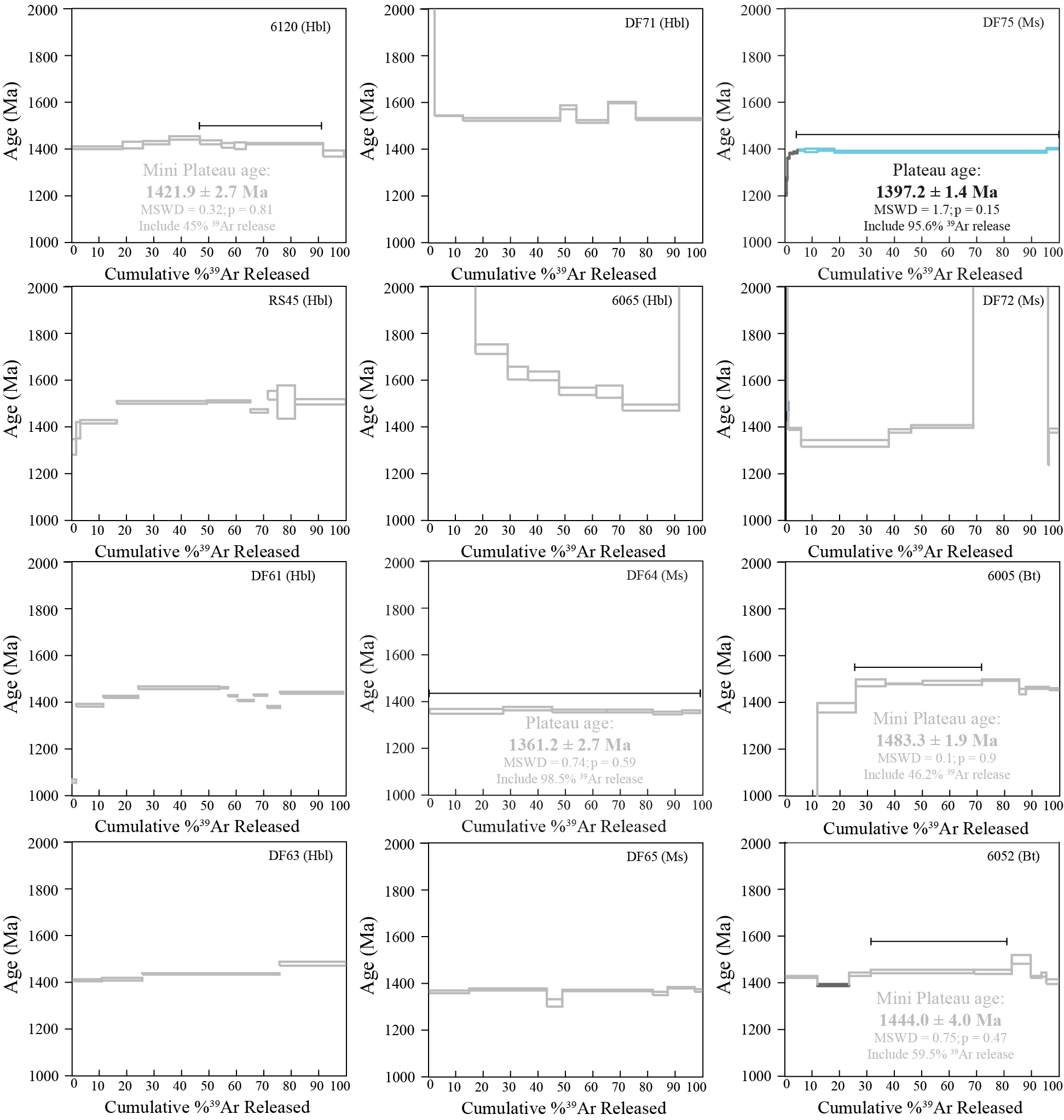


Figure S3. 40Ar/39Ar age spectra recalculatedfrom Spikings et al., [2001] using updated decay constant. Spectra with ages in light grey or no quoted ages are the 40Ar/39Ar results discarded in this paper. Whereas those we retained are shown with age plateaus in black (Bt) or blue (Ms). Specific sample information including sample lithology, locations, and stratigraphic positions are listed in Table S1.



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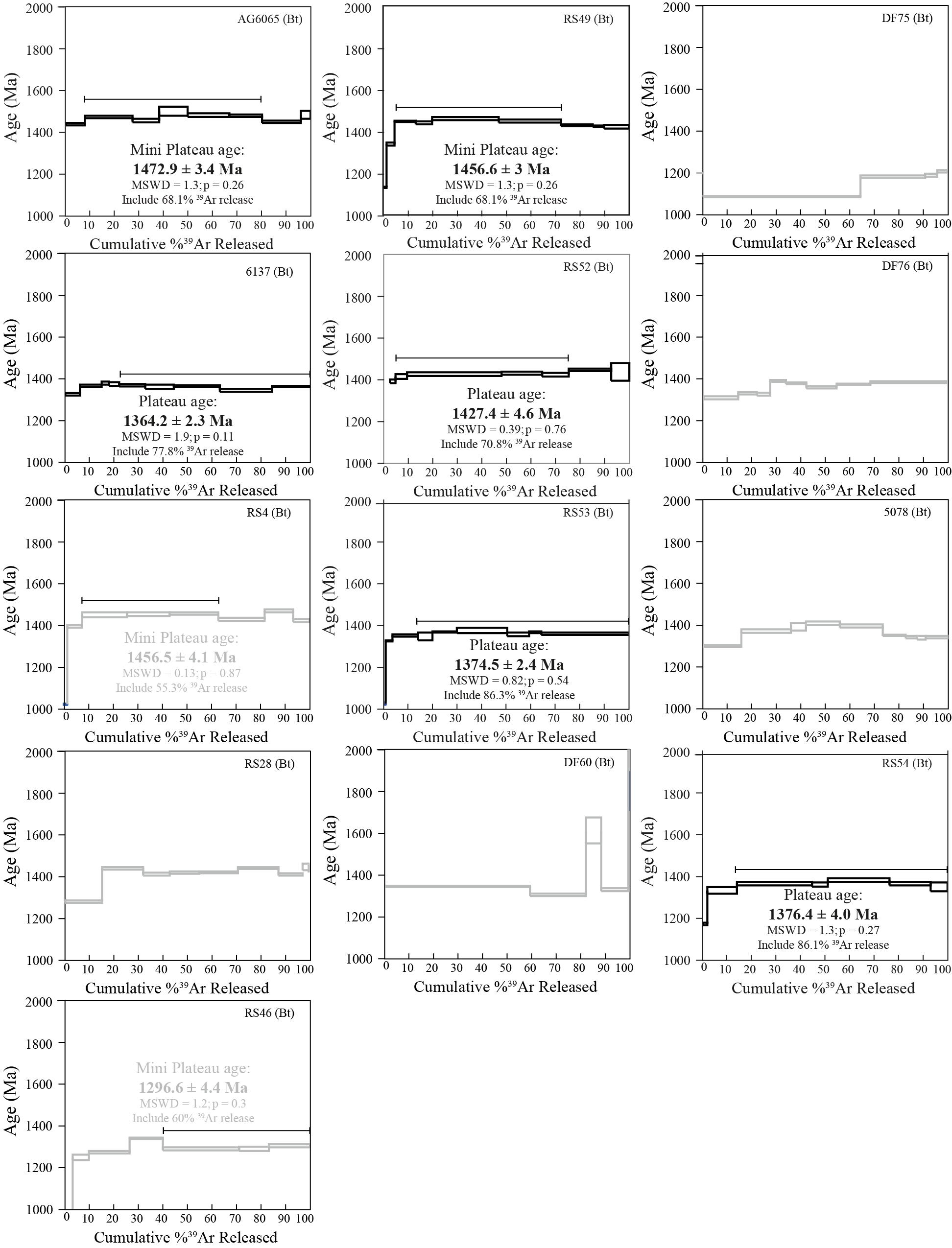


Figure S4. 40Ar/39Ar age spectra recalculatedfrom Spikings et al., [2002] using updated decay constant. Spectra with ages in light grey or no quoted ages are the 40Ar/39Ar results discarded in this paper. Whereas those we retained are shown with age plateau in black (Bt) or blue (Ms). Specific sample information including sample lithology, locations, and stratigraphic positions are listed in Table S1.

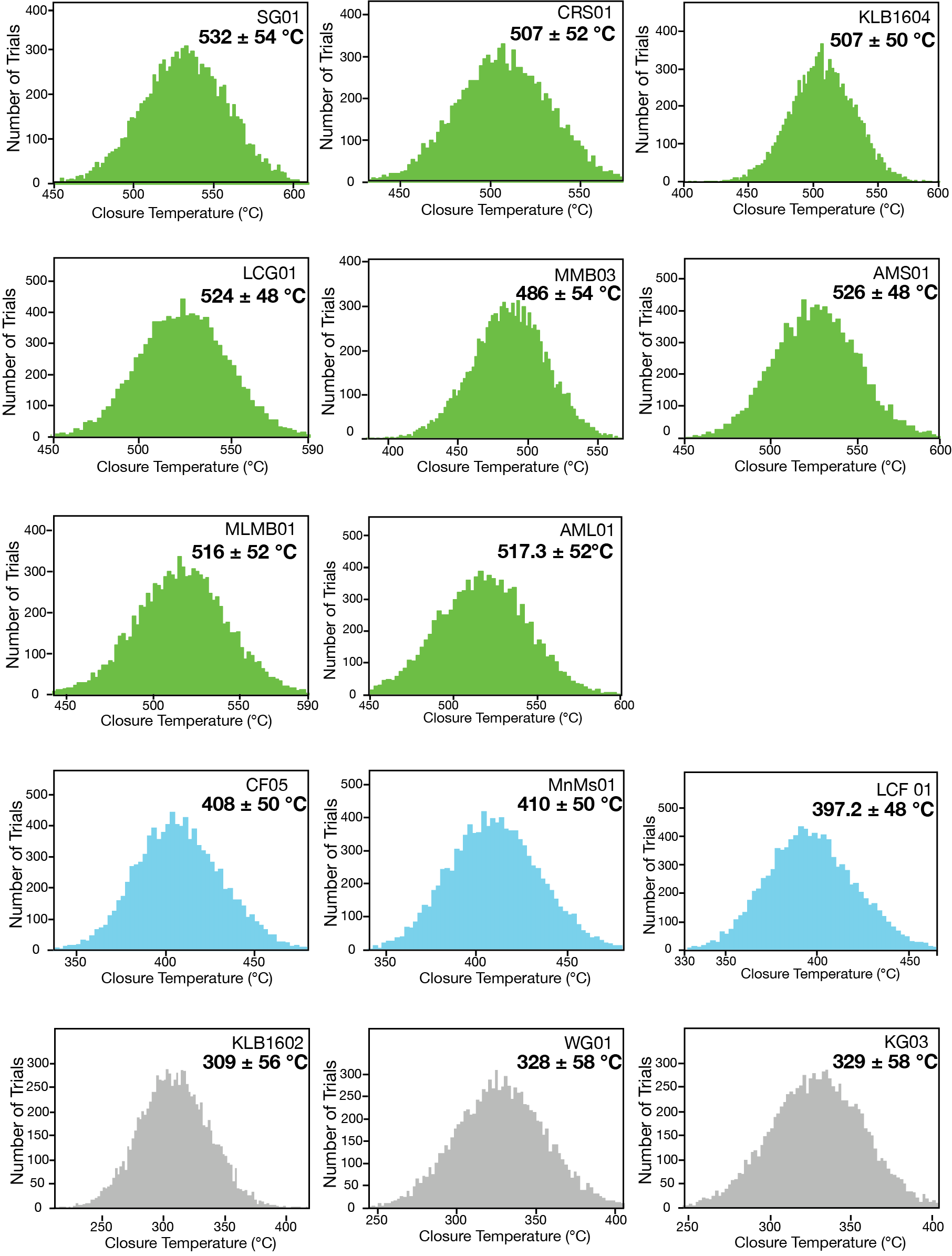


Figure S5. Probability diagrams of Monte Carlo simulation for 10,000 computations of the argon closure temperature in hornblende, biotite and muscovite from this study. The closure temperature values are reported at mean with 2 standard deviations.

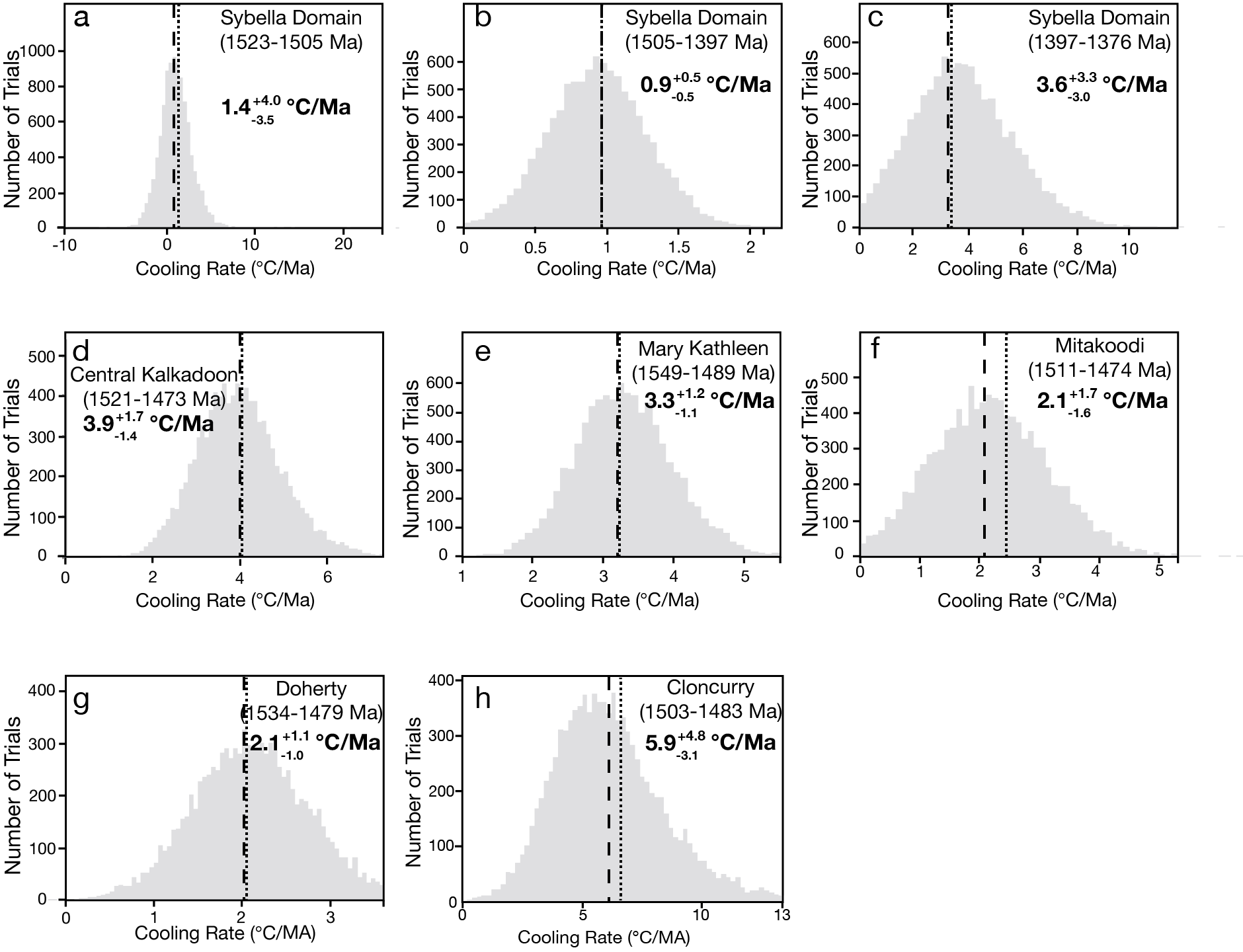


Figure S6. Probability diagrams of Monte Carlo simulation for 10,000 computation of the cooling rate between argon closure in hornblende, muscovite and biotite at different cooling stages. Mineral pair calculated in each domain include hornblende-hornblende (a); hornblende-muscovite (b, f–h); hornblende-biotite (d, e); muscovite-biotite (c). The cooling rate values are reported at mean with 2 standard deviations. Specific values for different stage are list in Table 1 in the main text. The dashed and dot line each represents the approximate location of the population median and mean.

Text S1. 40Ar/39Ar Thermochronology

Samples were crushed and sieved to extract 250–350 μm grains, which were then washed in acetone and rinsed with deionised water. Under a binocular microscope, optically fresh and homogeneous grains of hornblende, muscovite and micas were handpicked, while discarding grains exhibiting inclusions, fractures, and intergrowth of other minerals (especially chlorite). Hornblende aliquots were further leached in diluted HF and rinsed with distilled water in an ultrasonic cleaner.

Sample aliquots and reference Fish Canyon sanidine (FCs) (to monitor neutron flux) were loaded into the 14 large wells of an aluminium disc measuring 1.9 cm in diameter and 0.3 cm in depth. The discs were Cd-shielded and irradiated for 40 hours in Oregon State university nuclear reactor (USA) (Color, USA). For the FCs reference material, the age of 28.294 ± 0.036 Ma (1 standard deviation, SD) (Renne et al., 2011) was used.A neutron fluence parameter *J* value of 0.01078250 ± 0.00002264 was calculated from the mean J-values computed from standard grains within the small pits. An automated air pipette was used to monitor the mass discrimination and provided a mean value of 1.003786 ± 0.07 per dalton (atomic mass unit). The correction factors for interfering isotopes were (39Ar/37Ar)Ca = 7.30x10-4 (± 11%), (36Ar/37Ar)Ca = 2.82x10-4 (± 1%) and (40Ar/39Ar)K = 6.76x10-4 (± 32%).

All the 40Ar/39Ar analyses were conducted on single-grain aliquots, which maximises data accuracy as it enables determining 40Ar concentrations directly within single grains and prevents the mixing of different age populations. Isotope analysis was performed at the Western Australian Argon Isotope Facility at Curtin University. Single grains were step-heated using a 110 W Spectrum Laser System by rastering a continuous Nd-YAG (IR, 1064 nm) laser over the sample for 1 min for homogeneous heating. The released gas was purified in a stainless steel extraction line using two SAES AP10 getters, one GP50 getter, and a liquid nitrogen condensation trap. Argon isotopes in the released gas was measured in static mode with a MAP 215-50 mass spectrometer, with a Balzers SEV 217 electron multiplier using 9–10 cycles of peak hopping. Raw mass-spectrometer data were reduced using the Argus program written by M.O. McWilliams, and run under a LabView environment. Ages were calculated using the ArArCALC software [*Koppers*, 2002], considering the atmospheric or trapped 40Ar/36Ar ratio of 298.56 ± 0.3 [*Lee et al*., 2006] and a decay constant recommended by Renne et al. [2011].

Blanks were monitored every 3 to 4 steps and typical 40Ar blanks range from 1 x 10-16 to 2 x 10-16 mol. A blank was monitored after every 4 steps, with a typical 40Ar range of 3x10-16 – 5x10-16 mol. Ar isotope data corrected for blanks, mass discrimination, and radioactive decay can be found in Table S3 in the additional supporting information, with individual uncertainty given at 2σ. The criteria used to determine an age plateau are as follow: plateaus must contain >70% of the total measured 39Ar, with at least 3 consecutive stepsagreeing at 95% confidence level, and must satisfy a probability of fit (*p*) >0.05. Plateau ages are calculated using the mean of all plateau steps, reported with a 2σ uncertainty, each weighted by the inverse variance of their individual analytical error. Mini-plateaus are defined similarly but encompass only 50–70% of the measured 39Ar, and are considered less robust than plateau ages. All sources of uncertainties are included in the calculation.

Text S2. Monte Carlo Simulation

The Monte Carlo simulation was performed in Excel with an add-on program named Quantum XL (Sigmazone inc.), and produced 10,000 trials for each simulation. In each trial, Quantum XL selects a value randomly within the user-defined probability distributions. These values are then used to calculate closure temperature and cooling rate in Dodson [1973]’s equation. The cooling rate was recalculated after each iteration of the equation based on the newly calculated closure temperature. Closure temperatures value between minerals pairs (e.g. hornblende–muscovite) at 2σ may overlap, and produce large range of mathematically calculated values with unrealistic outliers. To minimize this effect, one standard deviation of the calculated closure temperatures is used to calculate the cooling rates within individual tectonic domains. Histograms showing the distribution of calculated closure temperatures and cooling rates are shown in Figure S8 and Figure S9 separately after 10,000 trials. These histograms represent the probability distribution of the true value of the variables calculated during the Monte Carlo simulation.

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