Analytical methods

Thin (30 μm) and thick (300 μm) sections were prepared for each sample from the same rock chip. Point counting (500 spots) on each thin section was completed using a standard petrographic microscope. Thick sections were examined on a Hitachi TM-1000 desktop SEM using backscattered electron (BSE) imaging. Individual grains of K-feldspar were identified and photographed without regard to size, alteration or exsolution textures. Each grain of sufficient size was then analysed for common Pb by laser ablation multi-collector inductively coupled plasma mass spectrometry (LA-MC-ICP-MS) at University College Dublin (UCD), using a ThermoScientific Neptune. A New Wave Research UP-193 Deep-UV ArF Excimer laser ablated spots of 75 μm along a c. 150 μm track after Tyrrell *et al.* (2012). Average ^{203}Tl/^{205}Tl-corrected ^{206}Pb/^{204}Pb in NIST 612 glass over 17 months was 17.102±0.064 (n=378, 2SD), and in Shap granite was 18.258±0.092 (n=85, 95%).

Zircon mounts were prepared using a minimum of steps to reduce the influence of operator bias on analytical results (Sláma & Košler, 2012). Up to ∼2 kg of rock were reduced to <500 μm using a jaw crusher and passed through methylene iodide to collect the heavy fraction. Grains were cast into mounts and polished to half height. Each zircon was photographed in BSE (UCD) and cathodoluminescence (CL; Portsmouth) imaging to identify growth zoning and contaminating features such as cracks and inclusions (Fig. 1). Because refractory minerals such as zircon are not easily destroyed by normal crustal processes, they frequently preserve two or more growth events within their structures. Since these growth events may be separated by millions of years, identifying the nature and location of any zoning ensures all data represent the same growth event, even when collected from different analytical spot locations.

U–Pb ages were measured by laser ablation quadropole mass spectrometry (LA-Q-ICP-MS) after Jeffries *et al.* (2003), using an Agilent 7500cs at the University of Portsmouth. Data were collected in three blocks during a period of renovation to the facilities, and so slightly different (but equivalent) methods were used in each block. In all cases, zircons were analysed in a ribbon pattern to avoid pre-selecting 'nice' grains (e.g. Mange & Maurer, 1992). Background signals were measured for 30 s, followed by 60 s of ablation. The amount of ^{204}Pb in these analyses was below the detection limit, and no common Pb correction was undertaken. All uncertainties were propagated in quadrature. Measured ^{207}Pb/^{235}U ratios are given unless signals were too low; these analyses are indicated as such in Supplementary Table 6. Only ages whose 2σ error envelopes overlapped Concordia (Fig. 2), measured in the youngest growth zone and avoiding irregular features such as cracks and inclusions, were used. Due to the differential decay rates of the parent isotopes, the sensitivity of each daughter ratio to change varies along concordia. As a result, ^{206}Pb/^{238}U ages are given if younger than 1200 Ma, and ^{207}Pb/^{206}Pb ages if older.

The first two blocks used a New Wave Research UP-213 Nd:YAG laser, employing a tear-drop cell (volume ∼2.6 cm^3) and a 30 μm spot rastered along a line. Typical gas flows were ∼1.5 L/min Ar and 300 mL/min He. Ratios in the first block were calculated using LAMTRACE v. 2.2 (Jackson, 2008), normalized to 91500 through sample-standard bracketing. Average ^{206}Pb/^{238}U and ^{207}Pb/^{206}Pb ratios of 91500 were 0.1792±0.0041 and 0.0749±0.0015 (n=137, 2SD), respectively, consistent with published values (Wiedenbeck *et al.*, 1995). GJ-1 was used as the internal standard, yielding ^{206}Pb/^{238}U and ^{207}Pb/^{206}Pb ratios of 0.0983±0.0024 (n=90, 95%) and 0.0602±0.0018 (2SD), respectively, consistent with published values (Jackson *et al.*, 2004).

Ratios in the second block were calculated using LamTool (Košler *et al.*, 2008), normalized to GJ-1 as no more 91500 was available. Average ^{206}Pb/^{238}U and ^{207}Pb/^{206}Pb ratios of GJ-1 were 0.0976±0.0023 and 0.0601±0.0020 (n=559, 2SD), consistent with published values. Plešovice was used as the internal standard, yielding ^{206}Pb/^{238}U and ^{207}Pb/^{206}Pb ratios of 0.0549±0.0036 (n=55, 95%) and 0.0536±0.0021 (2SD), respectively, consistent with published values (Sláma *et al.*, 2008). Previous work under the same conditions, using 91500 as the secondary standard before it was polished away, yielded ^{206}Pb/^{238}U and ^{207}Pb/^{206}Pb ratios of 0.1764±0.0040 and 0.0747±0.0024 (n=37, 2SD), respectively. The resulting average ^{207}Pb/^{206}Pb age of 1059±97 Ma (2SD) provides confidence that using such a young primary standard yields correct ^{207}Pb/^{206}Pb ages on Archaean samples, albeit with large uncertainties.

Ratios in the third block used a Resonetics RESOlution SE 193 nm Excimer laser fitted with the large-volume S-155 cell, and a 15 μm spot rastered along a line. Typical gas flows were 800 mL/min Ar, 700 mL/min He and 2.5 mL/min N_2. Ratios were calculated using LamTool, normalized to Plešovice. Average ^{206}Pb/^{238}U and ^{207}Pb/^{206}Pb ratios of Plešovice were 0.0539±0.0014 and 0.0532±0.0031 (n=237, 2SD), consistent with published values. GJ-1 and 91500 were used as internal standards, yielding ^{206}Pb/^{238}U ratios of 0.0984±0.0027 (n=60, 2SD) and 0.1804±0.0062 (n=32, 2SD), and ^{207}Pb/^{206}Pb ratios of 0.0589±0.0038 (2SD) and 0.0744±0.0057 (2SD), respectively, consistent with published values. The resulting average ^{207}Pb/^{206}Pb age of 1052±85 Ma (2SD) provides confidence that this method yields correct ^{207}Pb/^{206}Pb ages on Archaean samples.

Hafnium ratios were measured by LA-MC-ICP-MS at UCD, after Hawkesworth & Kemp (2006). Only grains with growth zoning of sufficient size and a concordant U–Pb age were analysed. 30–40 μm spots were drilled directly over the U–Pb craters, and each data cycle was examined for evidence of drilling into a different growth zone at depth. JMC-475 averaged ^{176}Hf/^{177}Hf = 0.282145±0.00004 (2SD), yielding an average correction of +0.000015. An exponential bias correction using ^{173}Yb/^{171}Yb was applied using an in-house spreadsheet. Mud Tank (Yb/Hf≈0.001) and GJ-1 (Yb/Hf≈0.01) cover the full range of Yb/Hf ratios observed in this study. Regular analyses of each produced JMC-corrected ^{176}Hf/^{177}Hf ratios of 0.282506±0.000024 (n=195, 2SD) and 0.281980±0.000042 (n=14, 2SD), respectively, consistent with published values Morel *et al.* (2008); Woodhead & Hergt (2005). ϵHf values and model ages were calculated based on a two-stage model, using the bulk Earth (chondritic uniform reservoir; CHUR) ^{176}Hf/^{177}Hf and ^{176}Lu/^{177}Hf from Bouvier *et al.* (2008), depleted mantle (DM) ^{176}Hf/^{177}Hf and ^{176}Lu/^{177}Hf from Griffin *et al.* (2002), and the Lu decay constant from Söderlund *et al.* (2004). A bulk crustal ^{176}Lu/^{177}Hf value of 0.015 is assumed (Griffin *et al.*, 2002). If the value of Chauvel *et al.* (2014) is used instead, individual model ages decrease by 100–300 Ma, but the overall conclusions do not change.

Heavy mineral separates were produced by gently disaggregating the sample in a mortar and pestle, taking care to minimise grain breakage, followed by ultrasonic treatment to enhance the disaggregation process and to remove surface coatings on grains. The 63–125 μm grain size fraction was extracted by sieving, and heavy minerals were separated by gravity-settling using bromoform. Heavy mineral grains were mounted under Canada Balsam for petrographic analysis with a split retained (where possible) for mineral chemical analysis. Detrital non-opaque heavy mineral proportions were estimated on the basis of a 200 grain count, with provenance-sensitive ratios determined on the basis of continued counting of the specific mineral pairs (Morton & Hallsworth, 1994).

Garnet major element compositions were determined by electron microprobe analysis at the Department of Geology and Petroleum Geology, Aberdeen University, UK. Grains were mounted on double-sided adhesive tape, coated with carbon, and analysed using a Link Systems AN10000 energy-dispersive X-ray analyser attached to a Cambridge Instruments Microscan V electron microprobe. The count time was 30 s per analysis. The quality of each result was monitored to ensure that the stoichiometrically-determined formulae corresponded to ideal garnet compositions. Garnet compositions are expressed in terms of the relative abundance of the Mg, Fe^{2+}, Ca and Mn end members, with Fe calculated as Fe^{2+}.

Rutile trace element compositions were determined by LA-Q-ICP-MS at the School of Earth, Ocean and Planetary Sciences, Cardiff University, UK. Grains were analysed using a Thermo Elemental X(7) series ICP-MS coupled to a New Wave Research UP-213 Nd:YAG laser. Analyses used a 30 μm spot and a laser repetition rate of 4 Hz, with a total acquisition time of 60 s per analysis, allowing about 30 s for background and 25 s for ablation. Thermo Elemental Plasmalab time-resolved analysis data acquisition software was used for initial data reduction, with post-processing completed in Excel. USGS basalt glass standards BIR-1G, BHVO-2G and BCR-2G were analysed to produce a 4 point (including the origin) calibration curve. Data were normalised to Ti (98% TiO_2). Instrumental drift was monitored by repeat analysis of BHVO-2G after every 25–30 grains. Source rock lithologies were determined from the resulting Cr/Nb ratios according to Meinhold *et al.* (2008), and Zr-in-rutile temperatures were calculated following Watson *et al.* (2006) as this method does not require an estimate of pressure conditions during growth, something that is impossible to determine in detrital grains. The external precision (2SD) on Cr/Nb ratios of BHVO-2G was 15.7% and 5.1% on Zr concentration, equivalent to a 12°C uncertainty on temperatures calculated from the highest concentrations.

Multi-dimensional scaling (MDS) is described in Vermeesch (2013), and expanded by Vermeesch & Garzanti (2015) to combine multiple lines of provenance evidence in a Procrustes analysis. Plots presented here were created using the `provenance` package for R. All data were imported with their stated 1σ uncertainties, applying the Sircombe & Hazelton (2004) kernel functional estimate method (`metric=''SH''`) to correctly compare data obtained by techniques with very different levels of precision (e.g. TIMS versus LA-ICP-MS). Where uncertainties were not stated in the original source, values were assumed as follows: ^{206}Pb/^{204}Pb by TIMS – 0.05%. U–Pb ages – 5 Ma.

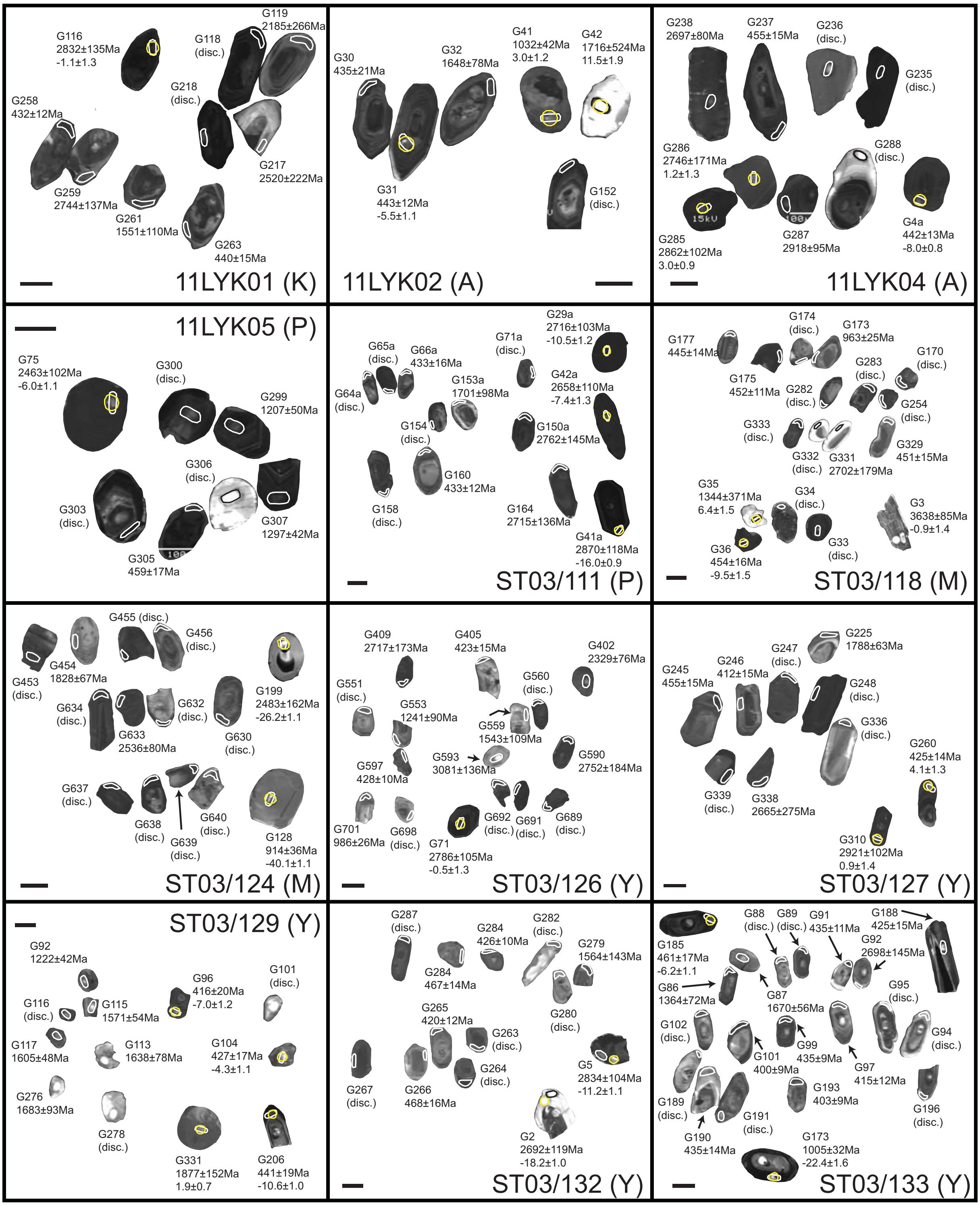
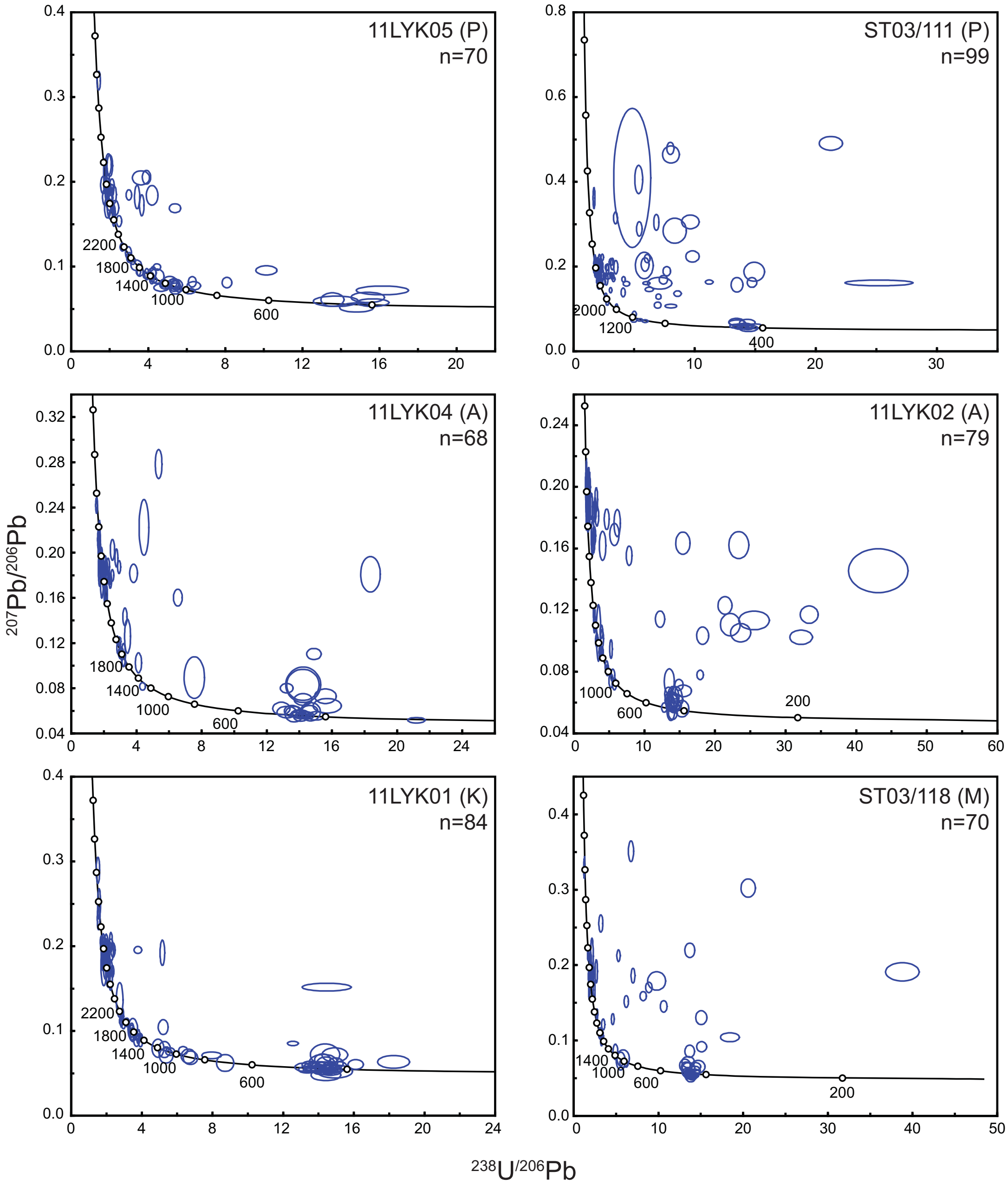


Figure 1: Typical CL images of zircons from this study, with analytical location(s) identified by grain name, concordant age and ϵHf value (uncertainties at 2SD). White spots - U–Pb. Yellow spots - Hf. disc. - discordant. All scale bars 100 μm.



11LYK05 (P)
n=70
ST03/111 (P)
n=99
11LYK04 (A)
n=68
11LYK02 (A)
n=79
11LYK01 (K)
n=84
ST03/118 (M)
n=70
2200
1800
1400
1000
600
2000
1200
400
200
$^{207}Pb/^{206}Pb$
$^{238}U/^{206}Pb$

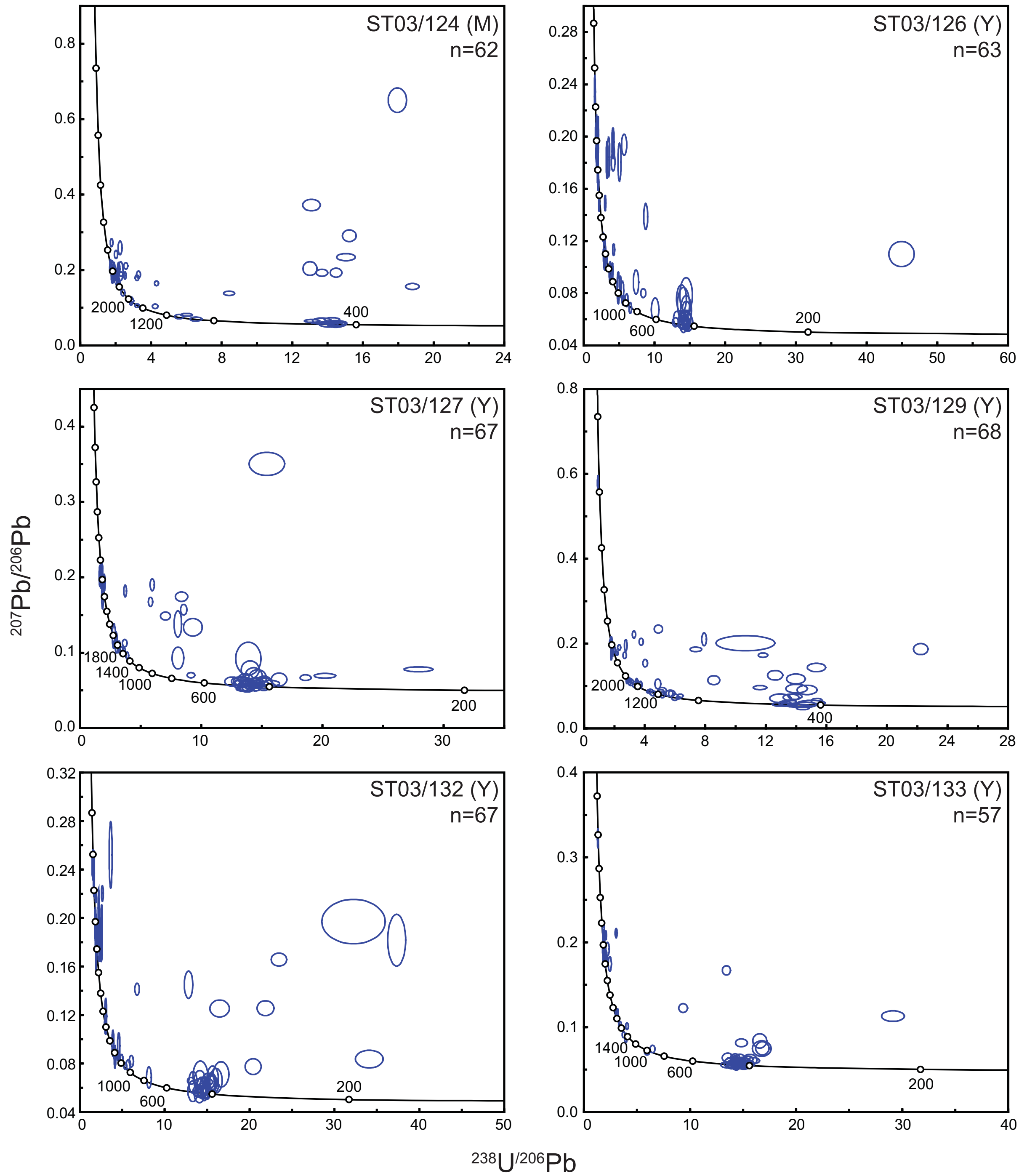


Figure 2: Terra-Wasserburg Concordia plots for zircons analysed in this study. All error ellipses are shown at 2σ.

References for Fig. 1

1. North America
   - Arth & Ayuso (1997); Ashwal *et al.* (1986); Ayer & Dostal (2000); Ayuso & Bevier (1991); Bowring *et al.* (1989); Davis *et al.* (1996); DeWolf & Mezger (1994); Dickin (1998); Doe (1962); Duane & de Wit (1988); Kamber *et al.* (2003); Loewy *et al.* (2003); Steiger & Wasserburg (1969); Tilton *et al.* (1955); Tilton & Steiger (1969); Whalen *et al.* (1996); Yamashita *et al.* (1999); Zartman & Wasserburg (1969)
2. Greenland
   - Connelly & Thrane (2005); Duane & de Wit (1988); Kalsbeek *et al.* (1993); Kamber & Moorbath (1998); Kamber *et al.* (2003); Pedersen *et al.* (2003); Stendal & Frei (2008); White *et al.* (2016)
3. Baltica
   - Andersen *et al.* (1994); Andersen (1997); Andersen *et al.* (2001); Birkeland *et al.* (1993*a*); Bjørlykke *et al.* (1993); Catanzaro & Gast (1960); Duane & de Wit (1988); Halla (2005); Heilimo *et al.* (2009, 2013); Lobach-Zhuchenko *et al.* (2008); Rämö (1991); Schärer & Labrousse (2003); Vaasjoki (1989); Vitrac *et al.* (1981); Weis & Demaiffe (1983)
4. UK and Ireland
   - Blaxland *et al.* (1979); Clayburn (1988); Dickin & Exley (1981); Dixon *et al.* (1990); Duane & de Wit (1988); Loewy *et al.* (2003); Marcantonio *et al.* (1988); Moorbath *et al.* (1975); Parnell & Swainbank (1984); Stephens & Halliday (1984); Thirlwall (1986); Tyrrell *et al.* (2006, 2007); Vitrac *et al.* (1981); Whitehouse (1989, 1990, 1993)

References for Fig. 5

1. Millstone Grit, Yorkshire
   - Cliff *et al.* (1991); Hallsworth *et al.* (2000)
2. East Greenland Caledonides
   - Detrital: Knudsen *et al.* (2001)
   - Granite: Hartz *et al.* (2000, 2001); Kalsbeek *et al.* (1993, 2000, 2001, 2008); Strachan *et al.* (1995, 2001); Thrane (2002); Watt *et al.* (2000)
3. Svaerholt sucession, Norway
   - Detrital: Kirkland *et al.* (2007)
   - Granite: Kirkland *et al.* (2006); Pedersen *et al.* (1989); Roberts *et al.* (2006)
4. Southern Uplands, Scotland
   - Detrital: Phillips *et al.* (2003); Waldron *et al.* (2008)
   - Granite: Pidgeon & Aftalion (1978)
5. Grampian Supergroup, Scotland
   - Detrital: Cawood *et al.* (2003)
   - Granite: Appleby *et al.* (2010); Dempster *et al.* (2002); Oliver *et al.* (2008)
6. NW Highlands, Scotland
   - Detrital: Lancaster *et al.* (2011)
   - Granite: Mendum *et al.* (2009)
7. Eleonore Bay Supergroup, E Greenland
   - Detrital: Dhuime *et al.* (2007); Watt *et al.* (2000)
   - Granite: Hartz *et al.* (2000, 2001); Kalsbeek *et al.* (1993, 2000, 2001, 2008); Strachan *et al.* (1995, 2001); Thrane (2002); Watt *et al.* (2000)
8. Krummedal supracrustals, E Greenland
   - Detrital: Kalsbeek *et al.* (2000); Leslie & Nutman (2003); Strachan *et al.* (1995); Watt *et al.* (2000)
   - Granite: Hartz *et al.* (2000, 2001); Kalsbeek *et al.* (1993, 2000, 2001, 2008); Strachan *et al.* (1995, 2001); Thrane (2002); Watt *et al.* (2000)

References for Fig. 6

Compiled by Lancaster *et al.* (2015).

1. N America
   - Amelin *et al.* (2000); Corfu & Noble (1992); Corfu & Stott (1993, 1996); Davis *et al.* (2005); Iizuka *et al.* (2009); LaFlamme *et al.* (2013); Pietranik *et al.* (2008); Smith *et al.* (1987); Stevenson & Patchett (1990)
2. Greenland
   - Amelin *et al.* (2000); Hiess *et al.* (2009); Knudsen *et al.* (2001); Næraa *et al.* (2012); Patchett *et al.* (1982); Stevenson & Patchett (1990); Vervoort *et al.* (1996)
3. Baltica
   - Andersen & Griffin (2004); Andersen *et al.* (2002, 2004, 2007, 2009); Heilimo *et al.* (2013); Heinonen *et al.* (2010); Kurhila *et al.* (2010); Lauri *et al.* (2011, 2012); Roberts (2010); Roberts *et al.* (2013); Petersson *et al.* (2015)
4. UK and Ireland
   - Appleby *et al.* (2010); Brewer *et al.* (2003); Flowerdew *et al.* (2009); Patchett *et al.* (1982); Stevenson & Patchett (1990); Whitehouse & Kemp (2010)

References for Fig. 7

1. North America
   - Aleinikoff *et al.* (1993); Arth & Ayuso (1997); Ayer & Dostal (2000); Ayuso & Bevier (1991); Bowring *et al.* (1989); Catanzaro & Gast (1960); Davis *et al.* (1996); DeWolf & Mezger (1994); Doe *et al.* (1965); Duane & de Wit (1988); Steiger & Wasserburg (1969); Tilton *et al.* (1955); Tilton & Steiger (1969); Yamashita *et al.* (1999); Zartman & Wasserburg (1969)
2. Greenland
   - Connelly & Thrane (2005); Duane & de Wit (1988); Jensen (1994); Kamber *et al.* (2003); Pedersen *et al.* (2003); Stendal & Frei (2008); White *et al.* (2016)
3. Baltica
   - Andersen (1997); Andersen *et al.* (2001); Birkeland *et al.* (1993*b*,*a*); Bjørlykke *et al.* (1993); Catanzaro & Gast (1960); Duane & de Wit (1988); Halla (2005); Heilimo *et al.* (2009); Lobach-Zhuchenko *et al.* (2008); Rämö (1991); Schärer & Labrousse (2003); Vaasjoki (1989); Zartman & Wasserburg (1969)
4. UK and Ireland
   - Blaxland *et al.* (1979); Clayburn (1988); Dixon *et al.* (1990); Duane & de Wit (1988); Lancaster & Storey (2016); Parnell & Swainbank (1984); Tyrrell *et al.* (2006, 2007); Whitehouse (1989)

References for Fig. 8

a. Pb MDS
   - S1 - NW and Grampian Highlands: Helmsdale granite (Tyrrell *et al.*, 2006); Strathspey and Strath Ossian granites (Clayburn, 1988); galena (Parnell & Swainbank, 1984)
   - S2 - Southern Uplands: Loch Doon, Cairnsmore of Fleet and Dalbeattie granites (Blaxland *et al.*, 1979)
   - S3 - Midland Valley: galena (Parnell & Swainbank, 1984)
   - E - N England: Shap granite (Tyrrell *et al.*, 2006); galena (Parnell & Swainbank, 1984)
   - I - Ireland: Donegal, Rosses, Thorr, Errisbeg Townland, Costello Murvey, Doolagh and Ox Mountain granites (Tyrrell *et al.*, 2007); galena (Dixon *et al.*, 1990; Kinnaird *et al.*, 2002)
   - O - offshore islands (Shetland, Orkney, Isle of Man): galena (Parnell & Swainbank, 1984)

- G - E Greenland: granite (White *et al.*, 2016); galena (Pedersen *et al.*, 2003; Jensen, 1994)
- N - Norway: Nordfjord UHP granulite (Schärer & Labrousse, 2003); Bindal batholith (Birkeland *et al.*, 1993*b*); Tinn granite (Andersen *et al.*, 2001); galena (Birkeland *et al.*, 1993*a*; Bjørlykke *et al.*, 1993)
- A - NE US: Maine (Doe *et al.*, 1965); Vermont (Arth & Ayuso, 1997); Grenville Front, Adirondacks (DeWolf & Mezger, 1994)
- C - Canadian Appalachians: New Brunswick (Ayuso & Bevier, 1991)

b. Caledonian U–Pb MDS

- All data from Slagstad *et al.* (2011), using same designations as in a.
- Sv - Svalbard

c. Archaean U–Pb MDS

- G - E, W and S Greenland: Andersen (2013); Kalsbeek *et al.* (1993); Næraa *et al.* (2012); Patchett *et al.* (1982); Stevenson & Patchett (1990); Strachan *et al.* (1995)
- S1 - Outer Hebrides, NW Scotland, Grampian Scotland: Friend & Kinny (1995, 2001); Whitehouse & Kemp (2010)
- I - Ireland: Flowerdew *et al.* (2009)
- N - Norway: Andersen *et al.* (2004)
- C - NE Canada: Condie *et al.* (2005); LaFlamme *et al.* (2013); Stevenson & Patchett (1990)

d. Caledonian Pb and U–Pb Procrustes

- Data as in a.–c., except:
- S1 - NW Highlands, Scotland
- S2 - Grampian Highlands, Scotland

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