Bin Deng, David Chew, Chris Mark, Liu Shugen, Nathan Cogné, Lei Jiang, Gary O'Sullivan, Zhiwu Li, and Jinxi Li, 2020, Late Cenozoic drainage reorganization of the paleo-Yangtze river constrained by multi-proxy provenance analysis of the Paleo-lake Xigeda: GSA Bulletin, <https://doi.org/10.1130/B35579.1>.

Supplemental Material

Figure S1. The confined AFT length distributions for four samples in the Xigeda formation. Note that all samples are roughly asymmetric unimodal in the distribution of length.

Figure S2. Tera-Wasserburg plots showing results of detrital U-Pb analyses in the Plio-Pleistocene Xigeda Formation. Data ellipses included in intercept calculations are red, blue, yellow and black; ellipses excluded as outliers are dashed gray. MSWD--mean square of weighted deviates. Error ellipses are 2σ .

Figure S3. Comparison of Miocene zircon U-Pb ages between sample SDB13 in this study (blue circles) and in Roger et al. (1995) (red circles).

Table S1. Heavy mineral abundance Data of Neogene Xigeda formation.

Table S2. apatite fission-track data of four samples in the Xigeda formation.

Table S3. Apatite U-Pb data of four samples in the Xigeda formation.

Table S4. Rutile U-Pb data in the Xigeda formation.

Table S5. zircon U-Pb data in the Xigeda formation.

Table S6. Trace-element data for detrital rutile in ppm.

Table S7. Sections of the Xigeda formation.

Table S8. All cited samples' location across the ST Tibetan Plateau.

1. Heavy mineral analysis and results

Heavy mineral analyses were employed to constrain the Plio-Pleistocene Xigeda formation sandstone provenance. Four heavy mineral separates were analyzed, comprising 3 samples from the Xigeda section and one sample from the Ganluo section, respectively. For each separate, more than 100 g of sample was disaggregated using a ceramic mortar and pestle, and wet-sieved into four grain-size categories: >1 mm, 0.25–1 mm, 0.0625–0.25 mm, and <0.0625 mm, and the 0.0625–0.25 mm sand fraction was then processed by density separation using sodium polytungstate with a density of 2.89 g.cm⁻³ (cf Morton, 1985; Mange and Maurer, 1992). Grains were mounted on glass slides using balsam resin, and a minimum of 250–300 opaque and translucent grains per slide were counted, with total counts exceeding 600 for most samples. A “ribbon-counting” method (Mange and Maurer, 1992) was undertaken using a Zeiss polarizing microscope with a 10X eyepiece and a 50X objective in conjunction with a mechanical point-counter. Muscovite and biotite were excluded from the heavy mineral counts, although chlorite was included as its abrupt appearance and abundance was considered significant for provenance determinations. Following point counting, the entire slide was examined for lithologically-significant trace accessory phases that could have been missed during the point counting procedure. Samples were then selected for apatite, rutile and zircon U-Pb dating based on their position within the stratigraphic section, the heavy mineral yield and the volume of sample. The samples for isotopic dating were disaggregated using a jaw crusher and disc mill followed by Wilfley table density separation, sieved to 0.25 mm and heavy mineral separation was then undertaken as described above.

The heavy mineral data are listed in Table S1. Heavy mineral assemblages are sensitive indicators of sediment provenance, but a variety of sedimentary processes may overprint the original provenance signal including weathering, hydrodynamics and diagenesis. We further employ the provenance-sensitive index ratios GZi, ATi, ZTR (zircon-rutile-tourmaline), RZi (rutile-zircon index) and MZi (monazite-zircon index) (Huber, 1962; Morton and Hallsworth, 1994) to help identify particular source rock types.

Table S1 Heavy mineral abundance Data of Neogene Xigeda formation

Samples	Location	Zi	Ap	Ru	An	Le	Mo	Sp	To	Ga	Il	Ma	He	Py	Ep	Ho	ZTR	ATi	GZi	RZi	MZi
XC0114	N26.55974 E101.90467 H=1700 m	3.42	0.17	0.11	0.06	0.04	-	3.42	0.02	4.63	8.27	3.57	1.84	0.02	14.70	59.71	3.55	88.89	57.56	4.76	-
XC0113	N26.56439 E101.89564 H=1780 m	3.41	0.57	0.24	0.73	0.16	-	2.60	0.00	5.61	9.34	0.88	1.87	-	15.88	58.70	3.66	99.98	62.16	22.22	-
XC0112	N26.56978 E101.88641 H=1680 m	7.03	1.84	0.16	0.16	4.08	0.00	5.94	0.02	10.46	38.64	9.93	0.80	-	11.27	9.66	7.21	98.78	59.82	4.32	0.00
SDB13	N28.955837 E102.760167 H=1600 m	7.18	1.46	0.60	0.44	0.31	-	3.47	3.59	5.28	17.66	11.22	-	-	24.17	24.62	11.37	28.83	42.36	12.66	-

(Note, Zi-zircon, Ap-apatite, Ru-rutile, An-anatase, Le-leucoxene, Mo-monazite, Sp-sphene, To-tourmaline, Ga-garnet, Il-ilmenite, Ma-magnetite, He-hematite-limonite, Py-pyroxenite, Ep-epidote, Ho-hornblendite. ZTR: zircon-tourmaline-rutile index (zircon + tourmaline + rutile counts), ATi: apatite-tourmaline index [$100 \times \text{apatite count}/(\text{total apatite} + \text{tourmaline})$], GZi: garnet-zircon index [$100 \times \text{garnet count}/(\text{total garnet} + \text{tourmaline})$], RZi: TiO₂ group + zircon index [$100 \times \text{TiO}_2 \text{ count}/(\text{total TiO}_2 \text{ group} + \text{zircon})$], MZi: monazite-zircon index [$100 \times \text{monazite count}/(\text{total monazite} + \text{zircon})$]).

2. Apatite Fission-track analysis

Fission tracks radiation-damage trails form in non-conductive materials (e.g., minerals and glasses) by the spontaneous fission of ^{238}U . On geological timescales, fission tracks in apatite anneal rapidly at temperatures above 120 °C and are almost stable at temperature below 60 °C, with the 60–120 °C temperature window defining the apatite Partial Annealing Zone (PAZ) (Gallagher et al., 1998; Reiners et al., 2005). Because the burial depth of the Neogene Xigeda Formation did not exceed a few hundred meters, we can rule out post-depositional thermal resetting of our samples. Apatite mineral separates were mounted in epoxy resin disks and polished to expose internal apatite grain surfaces. Spontaneous tracks were revealed by acid etching using 5.5 M HNO_3 at 21 °C for 20s, following the grain etching procedures described by Donelick et al. (2005). Fission-track counting was carried out using a Zeiss AxioImager Z1m microscope equipped with an Autoscan automated stage system at Trinity College Dublin, with more than 60 grains per sample. The long axes of the fission-track etch pits (Dpar) were also measured as a proxy for the compositional dependence of annealing (Carlson et al. 1999; Barbarand et al. 2003; Ketcham et al. 2007).

Apatite U concentrations for fission track dating were determined by LA-ICP-MS using a spot diameter of 30 μm with a repetition rate of 5 Hz and a fluence of 4.5 J/cm^2 to yield spot depths typically 15 μm deep. We followed a modified approach of the analytical protocol of Donelick et al. (2005). In contrast to the ICPMS absolute calibration approach of Hasebe et al. (2004), which employs the ^{238}U fission-decay constant, a fission track registration factor and a calibration factor for etching and observation, Donelick et al. (2005) used a modified zeta calibration approach (cf. Hurford and Green 1983) for ICPMS apatite U concentration measurements. The method assumes that the apatite ^{43}Ca signal intensity during a given LA-ICP-MS session acts as a proxy for the volume of apatite ablated, and hence the apatite $^{238}\text{U}/^{43}\text{Ca}$ ratio yields relative U concentration measurements. In this study an extensive primary LA-ICPMS session was undertaken on crystals of Durango apatite (31.44 ± 0.18 Ma (2σ), McDowell et al., 2005) that were previously counted for fission tracks to yield a primary LA-ICPMS zeta factor. The uncertainty on the calibration procedure (including the age uncertainty and the counting statistics related to the number of spontaneous tracks counted in the Durango standard) were propagated through to the final age calculation. These same crystals of Durango apatite were then analyzed in subsequent LA-IPCMS (along with apatite unknowns for fission-track dating) to yield a session-specific calibration factor on the primary zeta value. Inter-session drift in both the primary and subsequent LA-ICPMS sessions was corrected for by monitoring the $^{238}\text{U}/^{43}\text{Ca}$ ratio of NIST612 standard glass. The main difficulty in apatite fission-track dating by LA-ICPMS is ensuring that the uranium distribution with the portion of sample that generates fission tracks on the polished apatite surface is quantified spatially, both horizontally (i.e., along the surface of the grain mount) and vertically. The ablation spots were thus sited exactly over the counted area, while depth-related variations in U concentration were accounted for here by incorporating a function within the Iolite “Trace elements” data reduction scheme that weights appropriately the $^{238}\text{U}/^{43}\text{Ca}$ ratio with depth. As

LA-ICPMS is a destructive technique, high quality 3-D images of all the counted grains were archived for potential reinvestigation in the future.

Following the recommendation of Reiners et al. (2007), zero-track apatite grains were included in the analysis to avoid biasing the age component deconvolution, generating grains of nominal zero age. Track lengths were not measured because populations for thermal history modeling are very difficult to define in non-reset detrital samples; even where distinct populations can be identified, it is seldom possible to obtain enough track lengths. As many grains exhibited low U concentrations, track densities were often low and the grain age uncertainties were correspondingly high. AFT central ages and age components of overdispersed samples were determined using Radial Plotter (Vermeesch, 2009). The detailed apatite fission-track data of all four samples are listed in Table S2. It should be noted that all samples are roughly asymmetric unimodal in the distribution of length (Fig. S1).

Figure S1. The confined AFT length distributions for four samples in the Xigeda formation. Note that all samples are roughly asymmetric unimodal in the distribution of length.

Table S2 apatite fission-track data of four samples in the Xigeda formation.

Sample	#grains	Ns	ζ_{MS}	$1\sigma\zeta_{MS}$	$P(\chi^2)$	Pooled age (Ma)	$\pm 1\sigma$
XC0114	76	874	17.02	0.23	0	49.8	1.8

Grain	Ns	Area (cm2)	$^{238}\text{U}/^{43}\text{Ca}$	Is abs	FT Age (Ma)	$\pm 1\sigma$
Grain01	15	9.47E-06	3.08E-01	1.49E-02	43.6	11.5
Grain02	3	1.10E-05	1.19E-02	7.53E-04	192.7	111.9
Grain03	14	1.19E-05	3.63E-01	1.63E-02	27.4	7.4
Grain04	3	1.14E-05	6.85E-02	5.67E-03	32.5	18.9
Grain05	2	7.57E-06	4.99E-02	2.71E-03	44.9	31.9
Grain06	3	7.67E-06	1.26E-01	6.86E-03	26.5	15.4
Grain07	3	7.27E-06	2.55E-01	1.24E-02	13.8	8.0
Grain08	21	1.14E-05	4.49E-01	3.21E-02	34.7	7.9
Grain09	3	9.47E-06	6.42E-02	2.51E-03	41.9	24.2
Grain10	36	1.12E-05	4.85E-01	1.76E-02	56	9.6
Grain11	6	7.97E-06	6.47E-01	2.52E-02	9.9	4.1
Grain12	10	7.92E-06	1.51E-01	5.64E-03	70.9	22.6
Grain13	3	7.54E-06	1.74E-02	6.62E-04	191.8	111.0
Grain14	6	1.20E-05	3.36E-02	3.75E-03	125.4	51.5
Grain16	13	9.97E-06	3.36E-01	1.47E-02	33	9.3
Grain19	23	1.19E-05	1.09E-01	4.19E-03	149.8	31.8
Grain20	6	9.06E-06	8.90E-02	3.24E-03	63	25.8
Grain21	12	8.62E-06	1.22E-01	4.77E-03	96.4	28.1
Grain22	7	9.31E-06	1.87E-01	9.27E-03	34.1	13.0
Grain23	11	9.47E-06	1.90E-01	6.91E-03	51.9	15.8
Grain24	20	8.91E-06	4.79E-01	1.96E-02	39.8	9.1
Grain25	46	1.15E-05	7.12E-01	2.79E-02	47.8	7.3
Grain26	6	1.21E-05	8.59E-02	3.16E-03	48.8	20.0
Grain27	6	1.40E-05	1.45E-01	5.62E-03	25.2	10.3
Grain28	2	8.94E-06	8.43E-03	3.86E-04	221.8	157.2
Grain29	23	9.84E-06	2.51E-01	9.72E-03	78.7	16.8
Grain30	4	8.37E-06	1.26E-01	4.51E-03	32.1	16.1
Grain31	16	1.32E-05	2.12E-01	8.03E-03	48.5	12.3
Grain32	15	8.53E-06	3.59E-01	1.37E-02	41.6	10.9
Grain33	9	6.54E-06	2.54E-01	9.28E-03	45.9	15.4
Grain34	5	9.08E-06	1.13E-01	3.92E-03	41.4	18.6
Grain35	7	9.67E-06	6.86E-02	2.38E-03	89.3	33.9
Grain36	4	7.71E-06	1.17E-01	4.24E-03	37.7	18.9
Grain37	9	1.34E-05	1.86E-01	6.49E-03	30.7	10.3

Grain38	10	7.28E-06	4.51E-01	1.65E-02	25.9	8.2
Grain39	4	1.13E-05	7.57E-02	3.36E-03	39.6	19.9
Grain40	13	9.45E-06	2.82E-01	1.08E-02	41.4	11.6
Grain41	4	1.14E-05	4.97E-02	1.90E-03	59.9	30.0
Grain42	13	1.03E-05	2.18E-01	9.02E-03	49.2	13.8
Grain43	34	1.12E-05	1.86E-01	6.93E-03	137.3	24.2
Grain44	12	1.07E-05	2.07E-01	7.65E-03	45.8	13.4
Grain45	6	9.86E-06	5.80E-02	2.20E-03	88.6	36.3
Grain46	13	1.04E-05	2.52E-01	9.75E-03	42.2	11.8
Grain47	23	9.55E-06	5.58E-01	2.39E-02	36.7	7.8
Grain48	6	1.04E-05	1.37E-01	5.04E-03	35.9	14.7
Grain49	40	1.01E-05	1.70E-01	6.19E-03	196.3	32.0
Grain50	6	1.16E-05	2.37E-02	3.36E-03	183	75.1
Grain51	5	1.20E-05	6.62E-02	2.66E-03	53.4	24.0
Grain52	7	8.17E-06	5.45E-02	2.13E-03	132.4	50.3
Grain54	14	1.17E-05	2.90E-01	1.09E-02	35	9.5
Grain55	12	1.05E-05	2.08E-01	6.97E-03	46.6	13.6
Grain56	10	9.87E-06	1.41E-01	5.12E-03	60.9	19.4
Grain57	22	8.23E-06	1.05E-01	3.74E-03	213.2	46.2
Grain58	12	1.01E-05	6.64E-02	2.49E-03	150.6	43.9
Grain59	8	9.28E-06	5.94E-02	2.34E-03	122.4	43.6
Grain60	10	8.29E-06	2.59E-01	9.12E-03	39.5	12.6
Grain61	17	1.31E-05	2.03E-01	8.62E-03	54.4	13.4
Grain63	18	1.01E-05	2.12E-01	7.23E-03	71.4	17.0
Grain64	4	1.24E-05	4.02E-02	1.80E-03	67.8	34.1
Grain66	5	9.00E-06	6.47E-02	1.32E-02	72.7	32.7
Grain67	18	1.12E-05	3.54E-01	1.22E-02	38.7	9.2
Grain68	7	1.25E-05	9.21E-02	2.99E-03	51.5	19.6
Grain69	8	9.63E-06	1.42E-01	4.47E-03	49.7	17.7
Grain70	27	1.05E-05	4.54E-01	1.73E-02	48.2	9.5
Grain71	11	1.04E-05	2.19E-01	7.10E-03	41	12.5
Grain72	12	1.18E-05	1.85E-01	7.81E-03	46.6	13.6
Grain73	6	1.71E-05	7.86E-02	2.68E-03	37.9	15.5
Grain74	9	1.20E-05	1.26E-01	4.51E-03	50.5	17.0
Grain76	6	1.45E-05	2.34E-01	9.34E-03	15	6.2
Grain77	13	1.12E-05	2.23E-01	9.06E-03	44.4	12.5
Grain78	7	1.09E-05	4.20E-02	1.52E-03	128.9	49.0
Grain79	5	1.07E-05	1.21E-01	4.45E-03	32.8	14.7
Grain80	9	1.06E-05	1.11E-01	5.26E-03	64.9	21.8
Grain81	14	8.44E-06	5.16E-01	2.06E-02	27.3	7.4

Grain82	5	8.39E-06	1.32E-02	1.88E-03	374.1	168.0
Grain83	5	7.79E-06	1.06E-01	5.21E-03	51.5	23.2
Grain84	12	8.77E-06	8.09E-02	5.26E-03	142.3	42.1

Sample	#grains	Ns	ζ MS	$1\sigma\zeta$ MS	P(χ^2)	Pooled age (Ma)	$\pm 1\sigma$
XC0113	48	615	17.02	0.23	0	34.2	1.5

Grain	Ns	Area (cm2)	238U/43Ca	1s abs	FT Age (Ma)	$\pm 1\sigma$
Grain01	8	1.28E-05	1.90E-01	9.78E-03	28	10.0
Grain02	29	1.00E-05	3.32E-01	1.70E-02	73.9	14.3
Grain03	2	1.08E-05	1.45E-01	7.89E-03	10.9	7.7
Grain08	20	1.22E-05	5.49E-01	3.17E-02	25.5	5.9
Grain11	8	1.12E-05	1.41E-01	4.91E-03	42.7	15.2
Grain13	11	9.36E-06	2.51E-01	8.86E-03	39.7	12.1
Grain16	8	1.32E-05	1.03E-01	3.48E-03	50.3	17.9
Grain17	13	1.00E-05	2.91E-01	1.71E-02	37.8	10.8
Grain20	7	1.21E-05	8.11E-02	3.64E-03	60.5	23.1
Grain21	11	1.06E-05	4.85E-01	2.48E-02	18.2	5.6
Grain22	5	1.13E-05	9.81E-02	4.31E-03	38.3	17.2
Grain26	2	1.06E-05	1.64E-02	9.42E-04	97.4	69.2
Grain28	5	1.16E-05	1.54E-01	5.88E-03	23.7	10.7
Grain29	25	1.06E-05	4.47E-01	1.46E-02	44.9	9.1
Grain33	15	1.00E-05	4.22E-01	1.14E-02	30.2	7.9
Grain36	9	1.24E-05	2.48E-01	1.20E-02	24.8	8.4
Grain40	14	1.37E-05	1.43E-01	6.97E-03	60.5	16.5
Grain41	15	1.14E-05	5.83E-01	3.05E-02	19.1	5.1
Grain42	5	9.33E-06	7.68E-02	3.82E-03	59.1	26.6
Grain43	33	1.29E-05	6.74E-01	4.47E-02	32.4	6.0
Grain44	14	1.08E-05	2.81E-01	1.38E-02	39.3	10.7
Grain48	22	1.06E-05	3.21E-01	1.52E-02	54.6	12.0
Grain49	13	8.71E-06	3.69E-01	1.86E-02	34.3	9.7
Grain50	17	1.41E-05	3.09E-01	1.76E-02	33.3	8.3
Grain51	14	1.09E-05	3.34E-01	1.90E-02	32.6	8.9
Grain52	7	1.34E-05	1.86E-01	9.04E-03	24	9.2
Grain53	15	1.21E-05	3.03E-01	1.69E-02	34.6	9.2
Grain54	3	9.82E-06	8.43E-02	4.48E-03	30.7	17.8
Grain55	6	1.30E-05	8.04E-02	4.44E-03	48.6	20.0
Grain56	18	1.65E-05	2.50E-01	1.34E-02	36.9	8.9
Grain57	12	1.44E-05	2.72E-01	1.46E-02	26.1	7.7

Grain58	5	1.09E-05	2.03E-01	1.10E-02	19.1	8.6
Grain59	27	1.19E-05	5.15E-01	1.89E-02	37.3	7.3
Grain60	13	8.40E-06	1.41E-01	5.36E-03	92.7	26.0
Grain61	2	1.35E-05	2.65E-03	1.35E-04	459.3	325.8
Grain62	20	8.74E-06	2.29E-01	9.71E-03	84.6	19.3
Grain63	4	1.05E-05	2.82E-01	1.86E-02	11.5	5.8
Grain64	7	1.22E-05	4.12E-02	2.48E-03	117.5	45.0
Grain67	9	1.07E-05	2.36E-01	1.13E-02	30.1	10.2
Grain68	6	1.04E-05	4.31E-01	2.20E-02	11.3	4.7
Grain71	25	1.23E-05	4.19E-01	2.25E-02	41.2	8.6
Grain72	10	1.25E-05	1.84E-01	9.98E-03	37	11.9
Grain73	21	1.04E-05	1.07E+00	5.07E-02	16.2	3.6
Grain74	14	9.69E-06	1.70E-01	8.39E-03	71.8	19.5
Grain76	4	9.19E-06	1.79E-01	8.89E-03	20.7	10.4
Grain77	20	1.50E-05	2.40E-01	1.22E-02	47	10.8
Grain78	11	9.34E-06	4.96E-01	2.33E-02	20.2	6.2
Grain80	9	1.39E-05	1.18E-01	4.84E-03	46.7	15.7
Grain81	22	1.03E-05	3.64E-01	1.58E-02	50	10.9

Sample	#grains	Ns	ζ MS	$1\sigma\zeta$ MS	P(χ^2)	Pooled age	$\pm 1\sigma$
XC0112	67	815	17.02	0.23	0	37.9	1.4

Grain	Ns	Area (cm2)	$^{238}\text{U}/^{43}\text{Ca}$	1s abs	FT Age (Ma)	$\pm 1\sigma$
Grain01	22	4.01E-05	2.09E-01	6.28E-03	22.3	4.8
Grain03	6	1.71E-05	1.27E-01	3.25E-03	23.4	9.6
Grain04	4	1.89E-05	9.40E-02	5.50E-03	19.1	9.7
Grain06	5	1.04E-05	4.29E-02	1.10E-03	95.1	42.6
Grain07	5	1.72E-05	5.22E-02	1.56E-03	47.1	21.1
Grain08	3	8.99E-06	1.29E-01	4.46E-03	21.9	12.7
Grain09	4	9.75E-06	1.12E-01	4.54E-03	31.1	15.6
Grain10	16	1.31E-05	3.78E-01	1.22E-02	27.6	7.0
Grain11	9	1.50E-05	1.24E-01	4.00E-03	41	13.8
Grain12	9	1.11E-05	1.35E-01	4.17E-03	50.7	17.0
Grain13	3	1.44E-05	6.22E-02	2.09E-03	28.5	16.5
Grain15	5	1.24E-05	7.95E-02	7.56E-03	43.1	19.4
Grain16	11	1.35E-05	8.17E-02	1.95E-03	84.6	25.6
Grain17	8	9.56E-06	2.56E-01	1.19E-02	27.8	9.9
Grain19	19	1.37E-05	4.56E-01	1.15E-02	25.9	6.0

Grain20	6	1.18E-05	8.07E-02	2.19E-03	53.4	21.8
Grain21	9	1.42E-05	2.07E-01	5.24E-03	26.1	8.7
Grain23	5	1.81E-05	1.60E-01	3.89E-03	14.6	6.6
Grain25	21	1.17E-05	4.32E-01	1.08E-02	35.4	7.8
Grain27	32	8.98E-06	4.31E-01	1.02E-02	69.9	12.5
Grain28	5	1.05E-05	1.36E-01	3.63E-03	29.7	13.3
Grain29	3	8.70E-06	4.60E-02	1.81E-03	63.5	36.8
Grain30	3	1.30E-05	1.02E-01	2.57E-03	19.3	11.2
Grain32	33	1.02E-05	2.53E-01	6.16E-03	107.3	18.9
Grain33	19	1.14E-05	1.29E-01	6.48E-03	109.3	25.6
Grain34	9	1.19E-05	7.53E-02	4.32E-03	85	28.4
Grain35	2	9.96E-06	1.62E-02	1.08E-03	104.8	74.2
Grain37	7	1.02E-05	1.96E-01	5.19E-03	29.8	11.3
Grain38	7	1.24E-05	2.49E-02	2.84E-03	189.4	72.1
Grain40	17	1.63E-05	1.38E-01	1.09E-02	63.9	15.7
Grain41	18	1.18E-05	2.27E-01	1.15E-02	56.9	13.5
Grain42	30	8.92E-06	1.33E+00	3.68E-02	21.5	4.0
Grain43	2	9.67E-06	1.16E-02	2.95E-04	149.9	106.1
Grain44	17	1.13E-05	2.01E-01	5.18E-03	63.8	15.6
Grain47	8	1.02E-05	8.54E-02	2.77E-03	78	27.7
Grain49	3	1.10E-05	4.43E-02	1.51E-03	52.4	30.3
Grain50	2	8.49E-06	9.18E-02	2.31E-03	21.8	15.4
Grain51	10	1.23E-05	5.87E-01	1.48E-02	11.8	3.8
Grain52	16	1.22E-05	3.97E-01	1.18E-02	28.2	7.1
Grain54	12	9.92E-06	4.01E-01	1.68E-02	25.6	7.5
Grain55	20	1.25E-05	3.71E-01	1.07E-02	36.6	8.3
Grain56	29	1.49E-05	3.98E-01	1.02E-02	41.4	7.8
Grain57	8	1.41E-05	1.88E-01	5.09E-03	25.5	9.1
Grain60	12	8.68E-06	5.17E-01	1.88E-02	22.7	6.6
Grain61	18	9.77E-06	8.18E-02	2.67E-03	188.9	45.0
Grain62	11	9.02E-06	1.14E-01	3.35E-03	90.2	27.3
Grain63	4	1.04E-05	2.72E-02	2.64E-03	119.1	59.7
Grain64	8	1.16E-05	5.20E-02	4.00E-03	111.7	39.6
Grain65	17	1.24E-05	9.55E-02	5.68E-03	121.1	29.8
Grain66	10	1.07E-05	1.38E-01	4.71E-03	57.6	18.3
Grain67	15	7.79E-06	6.40E-01	1.93E-02	25.6	6.7
Grain68	5	7.62E-06	6.91E-02	2.12E-03	80.2	36.0
Grain69	12	1.50E-05	1.56E-01	4.32E-03	43.5	12.6
Grain70	9	8.73E-06	2.95E-01	1.29E-02	29.7	10.0
Grain71	20	1.15E-05	3.73E-01	9.88E-03	39.7	9.0

Grain72	7	8.64E-06	1.37E-01	3.97E-03	50.3	19.1
Grain73	25	1.23E-05	7.53E-01	2.17E-02	22.8	4.6
Grain74	7	1.35E-05	1.86E-01	5.85E-03	23.6	9.0
Grain75	8	1.86E-05	1.83E-01	5.83E-03	20	7.1
Grain76	14	1.08E-05	1.89E-01	5.61E-03	58.3	15.7
Grain77	7	1.90E-05	1.42E-01	4.98E-03	22.1	8.4
Grain78	22	1.13E-05	2.71E-01	8.88E-03	60.5	13.1
Grain79	15	1.51E-05	1.71E-01	5.72E-03	49.3	12.9
Grain80	29	1.16E-05	4.27E-01	1.17E-02	49.8	9.4
Grain81	28	1.05E-05	4.73E-01	1.27E-02	47.8	9.2
Grain82	17	1.34E-05	2.72E-01	7.39E-03	39.5	9.7
Grain83	13	1.70E-05	3.00E-01	7.35E-03	21.6	6.0

Sample	#grains	Ns	$\bar{\chi}$ MS	$1\sigma\bar{\chi}$ MS	P(χ^2)	Pooled age	$\pm 1\sigma$
SDB13	67	421	17.02	0.23	0	22.7	1.7

Grain	Ns	Area (cm2)	$^{238}\text{U}/^{43}\text{Ca}$	Is abs	FT Age (Ma)	$\pm 1\sigma$
Grain01	7	1.69E-05	6.99E-02	5.25E-02	50.1	42.2
Grain02	22	1.30E-05	3.67E-02	4.16E-02	381.6	116.5
Grain03	4	1.39E-05	6.91E-02	1.50E-02	35.4	19.3
Grain04	5	1.17E-05	1.06E-01	2.27E-02	34.1	16.9
Grain06	2	1.07E-05	1.07E-02	1.19E-02	147.8	109.2
Grain07	2	9.11E-06	8.50E-02	5.29E-02	21.9	16.4
Grain08	5	1.22E-05	1.85E-01	4.36E-02	18.8	9.4
Grain09	2	9.01E-06	3.56E-02	2.28E-02	52.8	39.0
Grain10	3	1.30E-05	1.88E-01	3.98E-02	10.4	6.4
Grain11	3	1.38E-05	1.07E-01	1.45E-01	17.2	10.6
Grain12	30	7.44E-06	4.84E-02	1.20E-01	672.3	199.4
Grain13	9	1.05E-05	1.11E-01	1.32E-01	65.3	25.9
Grain14	6	1.60E-05	2.19E-01	4.49E-02	14.5	6.7
Grain15	2	1.08E-05	8.03E-02	1.71E-02	19.7	14.7
Grain17	4	8.22E-06	5.68E-01	1.20E-01	7.3	4.0
Grain18	3	1.23E-05	1.00E-01	2.11E-02	20.7	12.7
Grain19	2	1.81E-05	4.65E-02	5.18E-02	20.2	14.9
Grain20	2	1.09E-05	8.81E-02	1.21E-01	17.7	13.1
Grain21	2	9.18E-06	4.11E-01	8.51E-02	4.5	3.3
Grain22	3	1.04E-05	3.52E-01	1.33E-01	7	4.3
Grain23	6	8.56E-06	7.09E-01	1.47E-01	8.4	3.9
Grain24	6	1.15E-05	6.25E-02	5.14E-02	70.6	32.4

Grain25	8	9.99E-06	6.09E-02	1.05E-01	111	45.9
Grain26	6	1.16E-05	7.47E-02	1.09E-01	58.9	27.2
Grain27	3	9.84E-06	9.66E-04	7.01E-04	2243.6	1407.3
Grain28	3	1.03E-05	3.72E-02	5.56E-02	66	40.6
Grain29	2	9.96E-06	3.73E-02	4.65E-02	45.6	33.7
Grain30	2	1.03E-05	1.08E-01	2.31E-02	15.3	11.3
Grain31	15	1.05E-05	4.01E-01	8.52E-02	30.4	10.1
Grain35	2	8.68E-06	4.41E-01	1.01E-01	4.4	3.3
Grain37	2	1.36E-05	3.60E-01	7.92E-02	3.5	2.6
Grain39	5	1.27E-05	1.43E-01	1.98E-01	23.4	11.6
Grain40	6	1.40E-05	4.15E-02	4.97E-02	87.1	40.1
Grain41	8	1.35E-05	3.61E-01	7.43E-02	14	5.8
Grain42	6	9.19E-06	5.91E-02	1.28E-02	93.3	43.1
Grain44	8	1.44E-05	2.58E-01	5.80E-02	18.2	7.6
Grain45	6	1.10E-05	1.32E-02	1.80E-02	340.3	157.6
Grain46	4	1.34E-05	3.57E-01	7.59E-02	7.1	3.9
Grain47	3	1.06E-05	3.51E-01	9.31E-02	6.9	4.3
Grain48	3	1.13E-05	4.70E-01	9.58E-02	4.8	3.0
Grain50	7	1.07E-05	1.05E-01	6.16E-02	53	23.1
Grain51	2	9.93E-06	3.46E-01	7.17E-02	4.9	3.7
Grain52	5	1.03E-05	1.10E+00	2.28E-01	3.8	1.9
Grain53	10	1.22E-05	1.66E-02	2.00E-02	408.2	155.6
Grain54	7	1.10E-05	3.36E-01	6.80E-02	16.1	7.0
Grain55	17	1.08E-05	1.12E+00	2.37E-01	12	3.9
Grain56	2	8.92E-06	4.21E-02	9.21E-03	45.1	33.4
Grain57	4	8.83E-06	1.00E-01	8.35E-02	38.3	20.8
Grain58	3	9.24E-06	1.08E+00	2.41E-01	2.6	1.6
Grain59	4	1.06E-05	2.49E-01	1.33E-01	12.9	7.0
Grain60	9	1.16E-05	3.63E-02	6.79E-03	178.9	75.6
Grain62	5	1.06E-05	6.10E-03	7.06E-03	626.4	310.8
Grain63	2	8.97E-06	6.84E-02	1.40E-02	27.7	20.5
Grain64	13	1.14E-05	4.94E-02	3.09E-02	193.5	67.7
Grain65	2	1.05E-05	2.60E-01	2.01E-01	6.2	4.6
Grain66	3	8.78E-06	3.00E-01	2.50E-01	9.7	6.0
Grain67	4	1.17E-05	5.77E-02	9.28E-02	50.4	27.6
Grain69	6	1.36E-05	1.16E-02	7.85E-03	315.2	146.7
Grain70	2	1.08E-05	2.39E-02	1.26E-02	65.6	48.4
Grain71	5	9.33E-06	4.76E-02	1.94E-02	95.1	47.3
Grain72	4	9.06E-06	1.04E-01	5.05E-02	36.1	19.6
Grain73	15	1.38E-05	1.03E-01	7.99E-02	89.1	30.2

Grain74	5	1.33E-05	4.61E-02	9.65E-02	68.9	35.3
Grain75	20	1.06E-05	5.41E-02	5.42E-02	291	91.4
Grain76	6	1.22E-05	3.67E-01	7.73E-02	11.4	5.3
Grain77	4	1.64E-05	5.68E-02	5.50E-02	36.4	19.8
Grain78	13	1.27E-05	6.29E-02	4.98E-02	136.9	48.2
Grain79	3	9.78E-06	8.64E-01	1.89E-01	3	1.9
Grain80	4	7.79E-06	1.30E-01	8.18E-02	33.6	18.2
Grain81	6	9.85E-06	4.45E-02	2.96E-02	115.5	53.0
Grain82	7	9.80E-06	2.79E-01	5.89E-02	21.7	9.4

3. Detrital apatite, rutile and zircon U-Pb dating and trace-element analysis

A minimum of 300 grains were hand-picked from the samples and mounted in epoxy resin. Eighty to one hundred grains is considered a minimum number of grains for statistically robust population characterization (Vermeesch, 2004). Samples were analyzed by a Thermo iCAP-QICP-MS coupled to a Photon Machines Analyte Excite 193 nm ArF excimer laser-ablation system at Trinity College Dublin. Each grain was analyzed for 45s with a 25 s washout which was employed for the baseline measurement. All data reduction was performed off-line using the IOLITE data reduction package with the VizualAge_UcomPbine (apatite and rutile) or VizualAge (zircon) data reduction schemes (Petrus and Kamber, 2012; Chew et al., 2014). Full details of the data reduction methodology can be found in Paton et al. (2011) and Chew et al. (2014). For apatite U-Pb analysis, the primary and secondary standards were the Madagascar apatite standard, and the McClure Mountain and Durango standards, respectively (Chew et al., 2014). For rutile, R10 was employed as the primary standard, and R19 and RZ3 were employed as secondary standards and treated as unknowns during data reduction (Luvizotto et al., 2009; Shi et al., 2012). Ages were calculated using the Isoplot plug-in for Excel (Ludwig, 2008). Common (non-radiogenic) Pb in the primary and secondary standards was corrected with a ^{207}Pb -based correction method using a known initial $^{207}\text{Pb}/^{206}\text{Pb}$ ratio; common-Pb in the unknowns was corrected using an initial estimate of the $^{207}\text{Pb}/^{206}\text{Pb}$ ratio generated using the terrestrial Pb evolution model of Stacey and Kramers (1975), after which an iterative approach was employed (Chew et al., 2011, 2014). Due to the use of the ^{207}Pb -based correction, apatite and rutile U-Pb analyses could not be conventionally assessed for discordance, but sometime the high common Pb to radiogenic Pb ratio resulted in undesirably large age uncertainties. Therefore, grains with ^{207}Pb -corrected 2σ errors $>25\%$ or 2σ errors $>50\%$ for grains younger than 100 Ma were excluded (cf Mark et al., 2016; O'Sullivan et al., 2016). For the zircon U-Pb analysis, either 91500 or Plesovice zircon, and Temora zircon were employed as the primary and secondary standards, respectively. As zircon typically incorporates only low quantities of common-Pb, a conventional discordance screening approach could be adopted. Analyses exhibiting $<20\%$ discordance or $>5\%$ reverse discordance of $^{238}\text{U}/^{206}\text{Pb}$ vs $^{207}\text{Pb}/^{206}\text{Pb}$ ages were excluded, following the approach of Gehrels (2012). All detrital U-Pb data are listed in Tables 3–5. Isotopic ages and Tera-Wasserburg Concordia generated using Isoplot (Ludwig, 2008) are listed in Figure S2.

For apatite and rutile trace-element analysis, the Trace_Elements DRS was employed in Iolite (Paton et al., 2011), which implements the internal elemental standardization approach of Woodhead et al. (2007). For rutile, the R10 rutile was utilized as the primary standard, and the R19 rutile was employed as a secondary standard and treated as an unknown; for apatite, NIST612 synthetic glass was employed as the primary standard, and Madagascar and Durango apatite as secondary standards.

Figure S2. Tera-Wasserburg plots showing results of detrital U-Pb analyses in the Plio-Pleistocene Xigeda Formation. Data ellipses included in intercept calculations are red, blue, yellow and black; ellipses excluded as outliers are dashed gray. MSWD—mean square of weighted deviates. Error ellipses are 2σ .

4. Rutile geochemistry

All rutile geochemical data are listed in Table S6. The rutile derived from either metamafic or metapelitic sources, exhibits chemical and physical stability during transport and diagenesis at both surface and high-grade metamorphic conditions (Force, 1980; Zack et al., 2004). Discrimination of rutiles derived from the above two sources is achieved using their trace element geochemistry (particularly Cr and Nb contents) (Zack et al., 2004; Meinhold et al., 2008; Triebold et al., 2012). In this article, we have classified rutiles with >800 ppm Nb and $\text{Cr} < \text{Nb}$ as metapelitic, and all others as metamafic, following the criteria proposed by Meinhold et al. (2008). Rutile formation temperatures have been estimated using the Zr content following the formula proposed by Watson et al. (2006).

Table S6 Trace-element data for detrital rutile in ppm.

Sample	Nb	$\pm 2\sigma$	Cr	$\pm 2\sigma$	Fe	$\pm 2\sigma$	Zr	$\pm 2\sigma$	U	$\pm 2\sigma$	Mg	$\pm 2\sigma$	Al	$\pm 2\sigma$	Temperature	Log(Cr/Nb)
X1=SDB13																
X1-1	4840	420	290	26	756	84	436	52	46.9	3	228	18	262	17	572	-1.22244736
X1-2	2100	190	1430	140	222	27	349	39	3.66	0.24	237	22	107.9	8.3	554	-0.16688326
X1-3	1550	240	1440	220	159	31	3400	1300	20.9	6.8	373	83	600	240	850	-0.03196921
X1-4	1980	170	999	81	501	53	238	23	13.8	0.69	224	21	145	15	522	-0.2970997
X1-5	5270	680	543	66	730	120	405	61	15.7	1.3	248	34	79	7.1	583	-0.98701079
X1-6	4100	240	793	44	566	37	506	32	27.7	1.5	217	11	68.8	3.7	542	-0.71351067
X1-7	3660	340	1340	110	369	37	271	26	24.2	1.4	226	19	144	11	529	-0.43637629
X1-8	2430	200	1330	120	432	46	479	44	30.5	1.8	209	16	136.9	8.8	561	-0.26175463
X1-9	7160	630	659	63	870	110	530	53	3.71	0.26	216	20	90.2	7.2	573	-1.03602761
X1-10	3660	340	505	39	452	48	335	38	10.82	0.64	220	20	162	15	552	-0.86018971
X1-11	6090	660	787	92	674	78	390	98	13.7	1.4	205	23	60.1	5.6	615	-0.88864256
X1-12	2750	350	820	140	356	87	26000	10000	65	24	217	39	98	28	1147	-0.52551884
X1-13	921	88	4110	410	112	13	145	14	3.27	0.23	201	18	58.3	4.9	495	0.64958219
X1-14	2970	260	1380	130	546	60	429	46	30	1.8	199	17	76.2	5.5	564	-0.33287736
X1-15	4220	310	613	46	671	65	481	43	7.41	0.39	185	14	131.3	8.6	560	-0.83785198
X1-16	254	19	66.7	5.7	708	61	347	66	36.3	1.9	183	13	49.2	3.2	588	-0.58070788
X1-17	2700	280	1020	110	630	76	192	21	5.1	0.34	186	21	29	2.6	517	-0.42276359
X1-18	1020	110	1030	110	149	17	2510	210	35.2	3	179	15	58	4.8	674	0.00423705
X1-19	1150	110	2670	230	167	21	80.6	7.5	1.01	0.077	270	78	64	26	463	0.36581342
X1-20	1450	110	3980	270	363	30	374	29	13.63	0.72	172	11	14.52	0.93	536	0.43851507
X1-21	4930	280	377	22	619	40	119.9	7.1	2.06	0.14	164.5	9.1	66.3	3	460	-1.11650557
X1-22	2630	100	1225	50	538	28	475	27	22.13	0.86	150.6	6.4	39.2	4.3	532	-0.33181966
X1-23	1069	56	46	16	541	30	315	17	6.32	0.26	232	27	1200	500	505	-1.36621987
X1-24	4720	210	928	38	833	38	204.4	9.1	17.55	0.45	151.5	6.4	42.5	2.3	472	-0.70639402
X1-25	2070	170	1043	78	468	41	257	84	5.65	0.67	181	20	960	530	605	-0.29768604

X1-26	5930	320	751	42	877	65	394	23	17.44	0.6	152	11	152.9	7.3	522	-0.89741476
X1-27	2770	230	1144	74	595	45	397	32	24.3	1.2	146	11	82.2	5.3	542	-0.38405374
X1-28	3360	250	598	39	984	85	358	28	69.8	3.5	147	10	61.4	4	534	-0.74963809
X1-29	5910	750	2610	320	632	79	930	120	10.8	1	156	21	114	11	630	-0.35494697
X1-30	2740	170	1232	79	590	45	800	53	13.5	0.65	149.7	9.5	36.9	2.4	573	-0.34713985
X1-31	3630	270	46.7	3.5	717	72	175	14	1.312	0.078	152	11	116.5	7.9	495	-1.89058974
X1-32	4000	260	506	30	925	67	399	32	17.56	0.71	151.3	9.6	79	5	542	-0.89790947
X1-33	3700	340	506	54	838	83	279	29	22.4	1.7	162	17	62.2	5.6	536	-0.86405121
X1-34	976	69	2850	230	1110	120	308	45	25.2	1.4	160	11	25.6	1.7	563	0.46539504
X1-35	5570	530	1028	91	862	92	288	32	16	1.1	151	15	61.2	5.5	542	-0.73386208
X1-36	3170	370	587	68	830	120	237	32	13.12	0.94	153	16	51.7	5.5	542	-0.73242116
X1-37	3300	200	383	17	966	58	510	210	19.9	1.9	150.6	7.4	35.7	2.1	674	-0.93531517
X1-38	740	110	1580	250	540	130	131	21	2.29	0.21	172	26	1750	620	517	0.32942537
X1-39	2410	180	696	47	728	61	456	38	7.43	0.4	151.7	9.4	193.1	9.6	552	-0.5394078
X1-40	3740	360	561	55	810	100	390	40	16.5	1.1	162	15	59.7	5.3	555	-0.82390874
X1-41	626	58	6420	610	111	12	46.8	4.7	2.99	0.23	163	14	1.37	0.25	440	1.01096069
X1-42	3710	290	152	11	1030	110	303	28	26	1.2	161	13	94.6	6.3	534	-1.38753032
X1-43	1980	190	1540	160	471	68	68.5	7.7	2.32	0.2	530	150	260	110	464	-0.10914447
X1-44	3530	390	741	86	1400	220	672	94	77	5.2	177	20	104.6	9.4	612	-0.6779565
X1-46	1480	140	3180	330	433	53	259	29	3.66	0.25	174	16	15	1.3	536	0.3321654
X1-47	594	64	1540	160	192	26	1370	170	13.45	0.98	175	18	50.5	4.2	657	0.41373428
X1-48	6110	510	1770	180	1230	140	279	34	42.3	3.3	277	28	710	150	545	-0.53806794
X1-49	5420	480	259	29	1310	170	303	33	15.8	1	176	16	98.8	8.2	544	-1.32069952
X1-50	566	48	424	42	1350	150	276	30	28.6	2.1	170	15	13.75	0.96	538	-0.12545057
X1-51	3420	310	837	76	1160	130	467	49	33.5	2.1	179	18	110.8	9.5	568	-0.61130065
X1-53	6850	650	910	95	1310	160	443	52	13.61	0.83	171	17	246	20	572	-0.87664918
X1-54	4590	300	271	18	1198	97	543	44	19.05	0.85	168	10	150	7.4	561	-1.22884339

X1-55	3360	370	302	34	950	130	373	46	15.8	1.1	172	20	138	15	564	-1.04633233
X1-56	3400	290	425	37	839	93	100.6	9.8	9.05	0.49	170	16	73.3	6.7	476	-0.90308999
X1-57	2440	230	1110	110	430	58	1230	150	14.43	0.78	172	17	56.2	6.5	647	-0.34206685
X1-58	3900	280	2330	200	257	29	353	33	11.27	0.71	171	13	50.4	3.8	544	-0.22370869
X1-59	2700	270	408	46	750	100	302	35	11.74	0.96	163	17	352	35	547	-0.8207036
X1-61	2120	270	4900	600	322	45	349	51	10.1	1.1	159	20	59.8	6.5	571	0.36386022
X1-62	590	110	3400	1000	1550	380	101	26	2.53	0.5	171	30	5.28	0.92	529	0.76062691
X1-63	4900	620	1280	150	830	120	127	17	0.358	0.025	160	21	133	14	505	-0.58298611
X1-64	3190	380	1090	160	1140	190	163	24	11.8	1	169	21	57.6	8	525	-0.46636419
X1-65	1990	270	2750	360	310	41	178	24	13.7	1.3	175	19	37.1	3.4	525	0.14047962
X1-66	4050	240	878	48	1037	87	309	22	16.49	0.64	158.7	9.5	41.5	2.4	520	-0.66396051
X1-67	2190	180	1280	110	356	36	250	26	1.79	0.15	160	13	23.2	1.9	529	-0.23323415
X1-68	4030	240	867	49	1072	77	271	20	13.84	0.68	170	11	118.3	7.3	514	-0.66728595
X1-69	2760	160	882	46	783	50	398	27	15.45	0.69	161.2	9.2	82.8	4.4	532	-0.4954405
X1-70	3770	200	475	28	1200	89	218	13	8.55	0.39	167	11	204	11	491	-0.89964774
X1-71	1232	74	749	46	731	58	353	26	30.5	1.3	170	11	12.5	1.3	529	-0.21612889
X1-72	1240	140	2220	300	478	77	76	11	9.76	0.9	175	27	29.5	3.5	482	0.25293129
X1-73	4390	380	452	38	1330	150	232	28	13.5	0.75	161	16	24.9	3	534	-0.98732609
X1-74	4750	320	1610	110	331	26	2840	210	98.1	3.6	161	11	150.6	7.3	674	-0.46986773
X1-75	1068	96	4720	430	237	27	18.9	2.1	0.311	0.028	161	15	8.8	6	405	0.64537075
X1-76	1000	110	6360	580	370	140	113.4	9.9	4.32	0.37	1920	820	124	50	476	0.80345712
X1-77	3290	340	587	62	1110	150	183	22	5.03	0.51	170	28	202	26	520	-0.7485578
X1-78	3560	150	873	37	1275	63	263	14	11.57	0.41	164.6	8.3	79.6	5.2	495	-0.61043575
X1-79	3960	380	298	20	1200	120	133	13	7.38	0.47	146	15	81.8	8.9	491	-1.12347892
X1-80	2770	290	378	43	1040	130	305	35	31.5	2.5	173	22	25.1	3.4	547	-0.86498797
X1-81	4090	390	649	64	1250	140	234	30	18.1	1.3	172	19	15.9	1.4	538	-0.79947861
X1-82	2410	230	647	61	641	83	836	87	6.02	0.36	292	57	2120	540	607	-0.57111276

X1-83	3740	360	1650	190	1020	150	455	56	31.6	2.3	156	17	35.4	3.7	577	-0.35538766
X1-84	3370	450	428	65	1220	230	264	41	13.8	1.3	158	21	80.5	9.9	557	-0.89618613
X1-85	860	110	4190	580	189	43	63	11	2.44	0.28	158	27	7.7	1.4	482	0.68771557
X1-86	671	78	332	33	1010	130	158	19	41.4	2.5	153	14	22	1.6	511	-0.30558444
X1-88	2230	130	223	15	1470	120	195	22	3.82	0.2	165	11	71.5	6.2	520	-1
X1-89	2020	210	642	74	1190	180	389	56	10.52	0.79	168	18	37.1	4.4	577	-0.49781634
X1-90	4050	780	620	110	1400	310	368	93	13.6	1.9	173	38	175	24	612	-0.81506333
X1-91	4330	480	1040	150	840	140	398	61	22.6	2.1	160	21	34.1	4.2	583	-0.61945456
X1-92	3810	500	516	73	1530	260	223	31	5.95	0.43	173	25	76.9	8.8	540	-0.86827527
X1-94	916	69	1270	100	501	52	157	13	66	3.4	160	10	23.8	1.5	491	0.14190825
X1-95	2040	300	179	27	870	210	148	26	9.6	1.2	176	29	134	18	529	-1.05677714
X1-96	1440	160	2280	260	447	72	31.5	4.4	0.37	0.046	416	94	146	51	437	0.19957235
X1-97	1050	120	2240	270	334	51	77	11	0.787	0.071	192	25	36.6	3.7	482	0.32905872
X1-98	1100	120	4960	590	483	88	76	9.9	1.9	0.17	204	22	117	14	476	0.65408899
X1-99	3250	410	457	61	1340	210	423	60	14.1	1.2	171	21	142	14	582	-0.85196716
X1-100	5400	1100	28.3	6.9	2550	600	234	51	136	19	159	32	48	10	571	-2.28060732
X1-102	2610	320	1010	220	1320	320	162	27	5.9	0.7	176	26	95	16	532	-0.41231913
X1-103	488	75	3410	380	800	140	107	13	2.82	0.24	2080	570	1160	330	491	0.84433456
X1-104	3250	250	1137	90	982	84	347	29	22.4	1.2	168	12	83.2	5.9	536	-0.4561229
X1-105	2380	260	836	79	863	91	390	38	22.1	1.2	171	18	35.1	3	552	-0.45437068
X1-106	2080	350	1140	180	1150	390	228	42	14.3	2.6	179	40	52.7	9.3	558	-0.26115848
X2=XC0114																
X2-1	3277	99	1730	56	984	32	540	19	28.15	0.85	203.4	7.2	55.7	4.1	758	-0.27743034
X2-3	2522	71	835	27	633	21	1344	43	26.89	0.55	467	18	169	40	854	-0.48005861
X2-4	947	32	157.8	5.2	415	28	70.6	2.1	1.18	0.048	283	19	541	95	593	-0.77824298
X2-5	2840	110	90.3	3.5	972	47	150.5	7.3	4.78	0.19	201	8.5	32	1.3	647	-1.49763059
X2-6	2521	79	1374	48	588	24	2058	71	13.17	0.47	201.3	5.9	43.1	1.2	906	-0.26358611

X2-7	2029	83	191.1	7.6	762	36	26.2	1.2	4.43	0.19	218.4	9.2	1020	210	530	-1.02602136
X2-8	1456	45	3260	120	87.8	3.5	2021	63	64	2	199.4	6.3	15.14	0.51	903	0.35005623
X2-9	461	18	143.7	5.4	772	31	182.1	7.4	9.31	0.37	203.6	7.4	103.9	3.2	662	-0.50624416
X2-10	683	24	127.2	4.6	549	24	156.9	4.9	0.347	0.031	220	10	57.4	7.3	651	-0.72993359
X2-11	1639	62	911	34	323	14	3370	120	59.2	1.9	200.5	7.4	174.1	8.1	972	-0.25506058
X2-12	6990	280	424	14	2780	180	40.1	2.5	5.13	0.18	1040	150	1220	190	556	-1.21711132
X2-13	2284	79	1175	42	1530	130	619	92	28.6	1	908	83	2160	230	771	-0.28865823
X2-14	1868	63	31.1	1.1	758	28	392	11	19.36	0.53	198.7	6.3	35.1	1.3	728	-1.77861648
X2-15	133.3	3	38.8	1.3	1070	37	491	12	23.17	0.56	208.4	7.3	112	16	749	-0.53599842
X2-16	232	11	43.1	2.1	564	26	90	19	0.226	0.023	206	10	59	6	609	-0.73101071
X2-17	1494	72	5400	210	238	16	24.06	0.82	7.38	0.33	336	16	2170	180	525	0.55804316
X2-18	1334	50	11350	450	73.5	7.5	36.4	1.4	5.25	0.25	210.1	9.6	410	140	550	0.92984003
X2-19	1426	39	3131	96	270.9	8	1483	38	8.03	0.21	199.5	6.1	35.4	1.1	866	0.34156354
X2-20	4480	140	2930	100	643	24	363	11	11.6	0.3	238	10	148	17	721	-0.18441039
X2-21	1130	46	2660	110	688	35	34.8	1.2	0.801	0.032	910	120	48	10	547	0.37180319
X2-22	444	33	4640	320	280	26	31.8	2.4	1.33	0.13	493	58	297	56	541	1.01913501
X2-23	2015	61	557	16	2178	86	84.4	6.2	1.052	0.045	322	44	1960	550	605	-0.55841986
X2-24	3990	150	1991	89	941	45	272	17	7.02	0.48	202.1	8	65.5	3.7	695	-0.30190164
X2-25	10700	320	1356	47	4230	180	1230	400	24.6	1.7	223.2	8.4	191	14	844	-0.89712409
X2-26	1083	30	199.6	6.6	468	16	92.9	3.3	1.203	0.084	198.5	6.5	72.6	2.6	612	-0.73446792
X2-27	416	16	110.9	3.3	757	27	117.7	4.1	8.71	0.35	274	17	345	80	629	-0.57416178
X2-28	2679	67	1252	31	881	24	582	15	27.84	0.61	201.2	4.8	29.6	1	765	-0.33036838
X2-29	1105	74	1366	55	1484	74	318	16	12.1	0.88	1554	53	17400	1900	709	0.09208842
X2-30	6380	160	962	22	1445	51	337	11	45	26	210	5.4	113.1	6.5	714	-0.82164561
X2-31	2790	130	533	14	1229	44	290	9.6	40.5	2.6	279	12	785	82	701	-0.71887699
X2-33	2330	120	1106	53	668	35	590	160	5.02	0.29	340	20	1000	160	766	-0.32360079
X2-34	2463	76	1825	50	471	14	332.2	9.3	9.87	0.28	243	13	1930	470	713	-0.13020154

X2-35	1475	64	1392	57	478	21	35.5	2	1.121	0.065	210.3	9.8	81	22	548	-0.02515279
X2-36	1206	28	41.9	1.5	714	20	1668	37	12.93	0.48	586	35	597	26	880	-1.45913328
X2-37	1487	51	896	37	706	24	954	33	77.7	2.4	203.7	6.7	32.9	1	816	-0.22000296
X2-38	1199	61	6640	310	630	41	21	1.3	0.34	0.035	2200	180	563	48	517	0.7433489
X2-39	2110	75	1513	52	579	60	822	30	31.9	1.2	452	40	770	120	800	-0.14444353
X2-40	2313	63	844	20	881	43	102.2	3	9.06	0.26	210.7	8	83	10	618	-0.43783319
X2-41	452	16	78.6	2.3	1280	180	183.8	6.1	6.87	0.2	960	290	1260	420	663	-0.75971589
X2-42	2587	99	309	11	863	46	289	12	10.69	0.52	310	18	376	47	701	-0.92283795
X2-43	884	48	323	24	694	26	63.6	2.4	1.52	0.063	200.8	6.7	72.2	2.9	585	-0.43724974
X2-44	3010	110	1041	41	1032	39	612	25	21.22	0.78	202.9	7.7	56.5	1.9	770	-0.46111577
X2-45	307	18	245	12	391	30	60.6	4.2	0.117	0.017	205.7	9.7	70.8	7.8	582	-0.09797229
X2-46	923	60	112.3	5	1583	79	640	250	0.408	0.05	216	14	134.8	8.6	774	-0.91482194
X2-47	850	20	233.4	7.4	1029	35	204.7	6.1	8.23	0.24	201.7	6	87.9	3.2	672	-0.56131807
X2-48	3252	94	657	20	989	40	2998	91	86.5	2.5	201	7.5	68.3	2.7	955	-0.69458517
X2-49	702	28	108.3	4.8	254	14	61.9	4.8	0.391	0.076	192	6.7	24.45	0.96	584	-0.81170866
X2-50	1048	44	1353	54	818	80	71.6	3.1	0.572	0.081	341	38	264	50	593	0.11093651
X2-51	2739	92	2409	85	164.3	7.3	1106	40	5.89	0.2	202.5	8.1	27.9	3.7	832	-0.05575523
X2-52	1471	70	913	42	726	31	391	19	12.5	0.53	213	9.1	333	31	727	-0.2071419
X2-53	517	16	3390	110	910	100	29.4	1.2	0.1056	0.0086	4130	400	2590	290	537	0.81670916
X2-54	5940	230	1792	67	887	42	1923	78	25.68	0.95	204.6	7.3	99.3	7.6	897	-0.52044844
X2-55	656	19	9800	230	401	82	12.77	0.45	0.292	0.018	3220	790	59	20	490	1.17432224
X2-56	928	28	6490	370	173.8	7.2	77.5	2.3	5.67	0.19	196.8	5.4	10.25	0.41	599	0.84469672
X2-57	746	24	810	25	3700	530	136	4.5	5.3	0.17	7300	1200	9400	1500	640	0.03574619
X2-58	878	32	3360	120	188.5	7.9	83.6	2.6	1.013	0.034	202.4	6.1	66	13	604	0.58284476
X2-59	714	46	144	4.6	1730	280	48.5	1.9	3.62	0.15	980	320	970	430	568	-0.69533572
X2-60	2272	52	1494	46	565	27	3870	240	84.9	3.3	298	18	2010	260	991	-0.18205773
X2-61	2263	79	1260	41	702	28	347	13	30	1.1	192.9	5.6	30.39	0.9	717	-0.25431401

X2-62	2618	85	99.4	4.4	1084	49	3500	1500	5.84	0.57	205.6	9.6	392	16	977	-1.42058326
X2-63	2197	80	989	48	940	100	1942	87	11.09	0.5	704	86	3990	510	898	-0.34663377
X2-64	2846	83	1216	49	1180	100	121.7	4.5	6.67	0.43	2140	310	13400	2400	631	-0.36930132
X2-65	167.9	9.4	470	13	671	35	83.7	2.9	0.36	0.028	493	28	2000	250	604	0.44704716
X2-66	3480	140	540	28	1102	59	112.6	4.9	5.5	0.27	281	18	1100	180	626	-0.80918548
X2-67	218.9	6.6	4270	120	860	250	181	15	10.25	0.5	3100	1100	27.7	2.2	662	1.29018211
X2-68	1295	39	225	6.5	1289	57	93	37	0.397	0.098	218.6	9.2	150	41	612	-0.76008725
X2-69	538	37	65.8	5	1810	230	720	170	1.87	0.43	3490	390	2470	310	786	-0.91255638
X2-70	2760	120	210.2	7.2	1379	56	132.3	7	41.8	2.7	243	17	147	18	638	-1.11827637
X2-71	2426	85	1817	76	636	28	562	32	38.7	1.8	208	11	50.5	5.7	762	-0.12553587
X2-72	990	36	193	8	626	25	161.9	6.5	8.14	0.3	198.1	8.4	122.6	8.2	653	-0.71007789
X2-73	640	26	354	15	1252	54	5500	500	27.7	1.8	292	25	2360	770	1045	-0.25717671
X2-74	1102	38	625	27	152	16	1155	53	20.65	0.92	256	18	341	45	837	-0.24630158
X2-75	726	27	2206	79	2350	180	37.1	1.5	0.626	0.035	4070	590	2130	320	551	0.48266889
X2-76	429	16	2029	79	3260	390	49.4	2.6	4.68	0.18	11200	2000	552	83	569	0.67482475
X2-78	1175	41	663	25	346	12	910	33	28.41	0.95	199.7	7.6	54.8	1.9	811	-0.24852434
X2-79	1202	44	448	31	4470	490	812	64	78.7	5.3	1010	500	6200	2500	799	-0.42862645
X2-80	1498	45	637	29	416	19	1334	64	11.65	0.44	204.2	9.1	78.2	3.2	853	-0.37137238
X2-81	1692	54	367	14	594	26	561	21	6.9	0.28	207.6	8.5	36.1	4.5	761	-0.66373429
X2-82	5070	170	857	43	1182	50	663	26	10.27	0.46	200.6	9.5	182.6	6	778	-0.77202714
X2-83	139.7	4.7	147.9	5.5	885	32	166.4	5.4	3.53	0.14	204.9	7.7	49	14	655	0.02477177
X2-84	300.8	9.7	304	14	355	16	393	16	5.98	0.23	239.8	9.4	548	56	728	0.00459575
X2-85	1187	45	9080	400	168.9	8.9	637	31	29.1	1.2	204.3	9.5	17.17	0.83	774	0.88363513
X2-86	1646	50	10750	400	281	26	23.92	0.92	9.26	0.37	223.7	9.6	541	79	524	0.81497863
X2-88	1136	37	924	28	407	13	817	25	16.86	0.55	199.5	6.6	112.5	3.9	799	-0.08970636
X2-89	1802	82	597	25	994	58	59.7	8	0.338	0.026	225	12	104.7	7.1	581	-0.47978046
X2-90	754	27	431	17	1857	81	466	18	1.042	0.053	268	25	96	13	744	-0.24289408

X2-91	256.7	7.9	87.4	3	539	21	160.9	6.8	0.9	0.046	196.4	5.9	41.8	1.7	653	-0.46791444
X2-92	1959	81	994	33	226	13	761	23	56.5	2	204.7	6.5	17.5	3.7	792	-0.29464805
X2-93	2436	63	1089	33	620	19	42.8	1.4	1.55	0.16	203.3	6.7	365	38	560	-0.3496494
X2-94	1059	41	251	12	1034	49	73.7	3.8	6.03	0.24	264	16	543	54	595	-0.62522224
X2-95	955	32	2641	93	256	13	1086	38	6.18	0.21	197.3	5.8	1200	260	830	0.44176503
X2-96	1849	51	1020	22	546	17	631	17	41.3	1.3	196.4	6.6	66.8	2.7	773	-0.25833674
X2-97	333.6	9.2	1411	45	641	28	353	74	1.075	0.061	210.9	7	102	25	718	0.62630097
X2-98	473	17	147.6	9.6	1340	120	125.6	4.9	7.54	0.86	3090	500	960	170	634	-0.50577478
X2-99	1402	49	652	32	1017	71	347	17	2.19	0.19	599	33	2360	320	717	-0.33250042
X2-100	78.4	3	6730	220	2580	310	141.4	7.1	1.7	0.14	5350	520	4690	560	643	1.933699
X2-101	320	12	1516	71	1630	100	27.8	1.1	0.32	0.028	1340	260	560	140	533	0.67554922
X2-102	1245	61	85.3	3.9	1710	200	114.3	5.1	8.46	0.41	1190	270	1250	320	627	-1.16422032
X2-103	485	36	158.1	9.9	959	71	56.5	4.3	2.95	0.29	1310	160	610	120	578	-0.48680987

Figure S3 Comparison of Miocene zircon U-Pb ages between sample SDB13 in this study (blue circles) and in Roger et al. (1995) (red circles).

Table S7 Sections of the Xigeda formation.

No.	Location	Outcrops elevation (m)	Thickness (m)	Age (Ma)	Reference
1	Luding	1850-2220	411.2	ca. 4.2-2.6	Jiang et al., 1999
2	Mianing	1970-2200	300.7	ca. 3.6-2.6	Zhao Z.Z. et al., 2007; Zhao X.T,2008;
3	Ganluo (GL)	1050-1250	56.4	--	Our data
4	Qiangxianping	1130-1240	172.4	ca. 3.2-2.2	Qian et al., 1984.
5	Xigeda(XGD)	1240-1300	88.5	ca. 3.2-1.8	
6	Laotaizhiliang	1070-1130	78.5	ca. 3.2-1.8	
7	Panzhihua	1050-1350	52.1	ca. 2.7-1.2	Zhao X.T,2008; Kong et al., 2009
8	Taoyuan	1200-1300		ca. >0.2	Zhu et al., 2018; BGMRYP, 1966.
9	Xiaolonggou	1530-1700	387	--	Long et al., 1988.
10	Zhoujiacun	1720-1950	290	--	
11	Decang	1480-1600	100	--	BGMRSP, 1965
12	Butuo	2400-2560	245	--	
13	Chuxiong	1920	40	--	BGMRSP, 1967.
14	Yonglang	1200-1300	~100		BGMRSP, 1966.
15	Miyi	1100-1600	~100		
16	Hongge	~1400	248	--	Luo and Liu, 1988.
17	Longjie	1900-2100	~140	--	BGMRYP, 1973.
18	Gucheng	1780-2000	~210	--	
19	Yuanmou	1220-1440	>50	ca. 3.1-1.3	BGMRYP, 1973; Yao et al., 2005.

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