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METHODOLOGIES

Zircons and titanites were mounted in 25 mm diameter epoxy resin mounts
The mounts were coated with a ca. 15 nm-thick layer of carbon.
Zircons were imaged by cathodoluminescence (CL) using a KE Developments Centaurus system attached to a Tescan Mira XMU Field Emission Scanning Electron Microscope (SEM) at the Centre for Microscopy and Analysis (CMA) at Trinity College, Dublin. An accelerating voltage of 10 kV and working distance of ca. 11.5 mm were employed.
Titanites were imaged by Backscattered-Electrons (BSE) using a KE Developments Centaurus system attached to a Tescan Mira XMU Field Emission Scanning Electron Microscope (SEM) at the Centre for Microscopy and Analysis (CMA) at Trinity College, Dublin. An accelerating voltage of 20 kV and working distance of ca. 18.5 mm were employed.

Petrology

The petrological study of the continental sandstones from the North Minwun Basin revealed 25-65% quartz, with monocrystalline more abundant than polycrystalline quartz, and 5-10% feldspar. Plagioclase and orthoclase are common, while microcline is rare. In some thin sections, sericite has replaced feldspar and calcite and clay are observed. Lithic fragments range from 10-30%, and include slate, phyllite, schist, siltstone, dolomite and limestone. A mixture of silt, hematite/magnetite, chlorite and clays form cement, which constitutes 15-30% of the rock. Heavy minerals (HM) such as zircons, titanites, rutiles, apatites comprise less than 1%.

Zircons:

LA-ICPMS elemental and U–Pb age from zircons were acquired using a Photon machines G2 193 nm ArF excimer laser-ablation system with a Helex 2-volume ablation cell coupled to a Thermo Scientific iCAP Qc, at the Department of Geology, Trinity College Dublin. The ICPMS instrument was tuned using NIST612 standard glass to yield Th/U ratios of unity and low oxide production rates (ThO+/Th+ typically <0.10%).
An ARIS variable-volume signal-smoothing device was used to mix the He aerosol with 0.5 l(m)-1 Ar make-up gas and a small volume of N2 (ca. 6 ml/m) to enhance signal sensitivity and reduce oxide formation (Table 1).
The Analyte Excite – iCAP Qc setup yields a washout with 90% signal reduction in less than 1.5 s. Seven isotopes (90Zr or 91Zr, 204Pb, 206Pb, 207Pb, 208Pb, 232Th and 238U) were acquired using fluence of ca. 1.4 J·cm^2 with a total duty cycle of 25 secs.
All experiments employed a 30x30 µm square spot (Table 1).

Table 1

Laser parameters	
Instrument	Photon Machines Analyte Excite ArF Excimer 193 nm
Washout and background	10 and 15 s
Laser repetition rate	10Hz
Spot size	30x30 µm
Energy	1.4 Jcm^2
Laser carrier gas	0.65 L/min He
Mass spectrometer parameters	
Instrument	Thermo Scientific iCAP Qc

Plasma RF power	1550 W
Plasma carrier gas flow	0.5 L/min
Isotopes measured	
with dwell times [ms] listed	^{91}Zr [2], ^{204}Pb [10], ^{206}Pb [30], ^{207}Pb [75], ^{208}Pb [10], ^{232}Th [10], ^{238}U [30]
Total duty cycle	25s acquisition 12s washout

Data reduction of the raw U-Pb isotope data was performed through the "VizualAge" data reduction scheme (Petrus and Kamber, 2012) in the freeware IOLITE package (Paton et al., 2011). Sample-standard bracketing was applied after the correction of downhole fractionation to account for long-term drift in isotopic or elemental ratios by normalizing all ratios to those of the U-Pb reference standards. Final age calculations and KDE plots were made using the Isoplot add-in for Excel (Ludwig, 2012) and Density Plotter 8.4 (Vermeesch, 2012). 91500 zircon ($^{206}Pb/^{238}U$ TIMS age of 1065.4 ± 0.6 Ma) (Wiedenbeck et al., 1995) was used as the primary U-Pb calibration standard. The secondary standards

- Temora-2 zircon ($^{206}Pb/^{238}U$ TIMS age of 416.8 ± 1.3 Ma; Black et al., 2003)
- Fish Canyon zircon ($^{206}Pb/^{238}U$ TIMS age of 28.478 ± 0.024 Ma; Schmitz and Bowring, 2001)
- WRS 1348 zircon ($^{206}Pb/^{238}U$ TIMS age of 526.26 ± 0.70; Pointon et al., 2012)

yielded LA-ICPMS$^{206}Pb/^{238}U$ ages of 416.2 ± 2.4 Ma, 28.10 ± 0.34 Ma and 527.1 ± 2.4 Ma respectively. In this study, the $^{206}Pb/^{238}U$ age was used for zircons younger than 1.2 Ga and the207Pb/206Pb age for zircons older than 1.2 Ga following Gehrels et al. (2006) and Gehrels (2014).

The Concordia threshold for the considered ages was placed at 10%. The Concordia values were calculated using the "CONCORDIA" function in ISOPLOT (Ludwig, 2012). This function creates an array function that returns the "Concordia" age for the conventional-Concordia ratios, errors, & error-correlation (see Ludwig, 1998). Input values are $^{206}Pb^*/^{238}U$, error, $^{207}Pb^*/^{235}U$, error, error-correlation, with LambdaErrs (TRUE to propagate the ^{235}U and ^{238}U decay-constant errors), and two optional Boolean variables (PercentErrs and SigmaLevel specifying the type of error input (default is absolute, 2σ). Output is a 2-rows x 4-columns range containing the Concordia Age, 2σ a priori age error, MSWD, and probability-of-concordance. The second row of cells contains captions for the values in the first row.

Titanites:

LA-ICPMS elemental and U–Pb age from titanites were acquired using a Photon machines G2 193 nm ArF excimer laser-ablation system with a Helex 2-volume ablation cell coupled to an Agilent 7900, at the Department of Geology, Trinity College Dublin. The ICPMS instrument was tuned using NIST612 standard glass to yield Th/U ratios of unity and low oxide production rates (ThO+/Th+ typically <0.12%).

An ARIS variable-volume signal-smoothing device was used to mix the He aerosol with 0.5 l(m)-1 Ar make-up gas and a small volume of N2 (ca. 6 ml/m) to enhance signal sensitivity and reduce oxide formation (Table 2).

Table 2

Laser parameters	
Instrument	Photon Machines Analyte Excite ArF Excimer 193 nm
Washout and background	10 and 15 s
Laser repetition rate	12Hz
Spot size	47x47 µm

Energy	2.25 Jcm^{2}
Laser carrier gas	0.5 L/min He
Mass spectrometer parameters	
Instrument	Agilent 7900
Detection system	Dual-mode discrete dynote electron multiplier
Plasma RF power	1550 W
Plasma carrier gas flow	0.65 L/min
Isotopes measured	
Isotopes measured with dwell times [ms] listed	$_{91}$Zr [2], $_{204}$Pb+Hg [10], $_{206}$Pb [30], $_{207}$Pb [75], $_{208}$Pb [10], $_{232}$Th [10], $_{238}$U [30], $_{1776}$Hf [30], $_{56}$Fe [30], all REE [0.3]
Total duty cycle	25s acquisition 12s washout

The raw isotope data were reduced using a modified version of the "Vizual Age" data reduction scheme (Petrus & Kamber, 2012) of the freeware IOLITE package of Paton et al. (2011). This data reduction scheme ("VizualAge_UcomPbine") can account for variable common Pb in the titanite standard materials (Chew et al., 2014). User-defined time intervals are established for the baseline correction procedure to calculate session-wide baseline-corrected values for each isotope. The time-resolved fractionation response of individual standard analyses is then characterized using a user-specified down-hole correction model as an exponential curve, a linear fit, or a smoothed cubic spline). The data reduction scheme then fits this appropriate session-wide "model" U—Th—Pb fractionation curve to the time-resolved standard data and the unknowns. Sample-standard bracketing is applied after the correction of down-hole fractionation to account for long-term drift in isotopic or elemental ratios by normalizing all ratios to those of the U—Pb reference standards. Final age calculations and KDE plots were made using the Isoplot add-in for Excel (Ludwig, 2012) and Density Plotter 8.4 (Vermeesch, 2012).

OLT-1 (^{206}Pb/^{238}U TIMS ages of 1014.8 ± 2.0 Ma; Kennedy et al., 2010) was used as the primary U-Pb calibration standard. The secondary standards

- MKed1 titanite (^{206}Pb/^{207}Pb TIMS age of 1521.02 ± 0.55 Ma; Spandler et al., 2016)
- BLR titanite (^{206}Pb/^{207}Pb TIMS age of 1047.1 ± 0.4 Ma; Aleinikoff et al., 2007)

yielded LA-ICPMS ages of 1057.1 ± 15 Ma and 1535.9 ± 25 Ma respectively. Due to the ^{207}Pb-based correction, no titanite U-Pb age data can be excluded based on discordance criteria. However, the low-U content (sometimes <1 ppm) and consequent near-zero radiogenic Pb content of some titanite grains can result in large analytical uncertainties (or negative ages). We therefore excluded grains with 2σ errors >25%, similar to the approach of Zattin et al. (2012).

Apatites:

LA-ICPMS elemental and U–Pb age from apatites were acquired using a Photon machines G2 193 nm ArF excimer laser-ablation system with a Helex 2-volume ablation cell coupled to an Agilent 7900, at the Department of Geology, Trinity College Dublin. The ICPMS instrument was tuned using NIST612 standard glass to yield Th/U ratios of unity and low oxide production rates (ThO+/Th+ typically <0.12%).

An ARIS variable-volume signal-smoothing device was used to mix the He aerosol with 0.4 l(m)-1 Ar make-up gas and a small volume of N2 (ca. 6 ml/m) to enhance signal sensitivity and reduce oxide formation (Table 2).

Table 2

Laser parameters

Instrument	Photon Machines Analyte Excite ArF Excimer 193 nm
Washout and background	10 and 15 s
Laser repetition rate	12Hz
Spot size	47x47 µm
Energy	2.25 Jcm^2
Laser carrier gas	0.5 L/min He
Mass spectrometer parameters	
Instrument	Agilent 7900
Detection system	Dual-mode discrete dynote electron multiplier
Plasma RF power	1550 W
Plasma carrier gas flow	0.65 L/min
Isotopes measured	
Isotopes measured with dwell times [ms] listed	${}_{31}$P (1), ${}_{43}$Ca (1), ${}_{51}$V (0.75), ${}_{55}$Mn (0.75), ${}_{75}$As (1.5), ${}_{88}$Sr (0.75), ${}_{89}$Y (0.5), ${}_{90}$Zr (1), ${}_{139}$La (0.5), ${}_{140}$Ce (0.5), ${}_{141}$Pr (0.5), ${}_{146}$Nd (0.5), ${}_{147}$Sm (0.75), ${}_{153}$Eu (1), ${}_{157}$Gd (1), ${}_{159}$Tb (1), ${}_{163}$Dy (1), ${}_{165}$Ho (1), ${}_{166}$Er (1), ${}_{169}$Tm (1), ${}_{172}$Tb (1), ${}_{175}$Lu (1.5), ${}_{202}$Hg (0.5), ${}_{204}$Pb+Hg (0.5), ${}_{206}$Pb (7.5), ${}_{207}$Pb (7.5), ${}_{208}$Pb (0.5), ${}_{232}$Th (0.5), ${}_{238}$U (7.5)
Total duty cycle	25s acquisition 20s washout

The raw isotope data were reduced using a modified version of the “Vizual Age” data reduction scheme (Petrus & Kamber, 2012) of the freeware IOLITE package of Paton et al. (2011). This data reduction scheme (“VizualAge_UcomPbine”) can account for variable common Pb in the titanite standard materials (Chew et al., 2014). User-defined time intervals are established for the baseline correction procedure to calculate session-wide baseline-corrected values for each isotope. The time-resolved fractionation response of individual standard analyses is then characterized using a user-specified down-hole correction model as an exponential curve, a linear fit, or a smoothed cubic spline). The data reduction scheme then fits this appropriate session-wide “model” U—Th—Pb fractionation curve to the time-resolved standard data and the unknowns. Sample-standard bracketing is applied after the correction of down-hole fractionation to account for long-term drift in isotopic or elemental ratios by normalizing all ratios to those of the U—Pb reference standards. Final age calculations and KDE plots were made using the Isoplot add-in for Excel (Ludwig, 2012) and Density Plotter 8.4 (Vermeesch,2012).

Madagascar (^{206}Pb/^{238}U TIMS ages of 473.5 ± 0.7 Ma; Thomson et al., 2012) was used as the primary U-Pb calibration standard. The secondary standards

- Durango titanite (^{206}Pb/^{207}Pb TIMS age of 31.44 ± 0.18 Ma; McDowell et al., 2005)
- McClure titanite (^{206}Pb/^{207}Pb TIMS age of 523.51 ± 0.4 Ma; Schoene & Bowring 2006)

yielded LA-ICPMS ages of 32.58 ± 0.63 Ma and 527.3 ± 6.2 Ma respectively. Due to the ^{207}Pb-based correction, no titanite U-Pb age data can be excluded based on discordance criteria. However, the low-U content (sometimes <1 ppm) and consequent near-zero radiogenic Pb content of some apatite grains can result in large analytical uncertainties (or negative ages). We therefore excluded grains with 2σ errors >25%, similar to the approach of Zattin et al. (2012).

BIBLIOGRAPHY

Aleinikoff, J. N., Wintsch, R. P., Tollo, R. P., Unruh, D. M., Fanning, C. M., & Schmitz, M. D. (2007). Ages and origins of rocks of the Killingworth dome, south-central Connecticut:

Implications for the tectonic evolution of southern New England. *American Journal of Science*, *307*(1), 63-118.

Black, L. P., Kamo, S. L., Allen, C. M., Aleinikoff, J. N., Davis, D. W., Korsch, R. J., & Foudoulis, C. (2003). TEMORA 1: a new zircon standard for Phanerozoic U–Pb geochronology. *Chemical geology*, *200*(1-2), 155-170.

Chew, D. M., Petrus, J. A., & Kamber, B. S. (2014). U–Pb LA–ICPMS dating using accessory mineral standards with variable common Pb. *Chemical Geology*, *363*, 185-199.

Gehrels, G. E., DeCelles, P. G., Ojha, T. P., & Upreti, B. N. (2006). Geologic and U–Pb geochronologic evidence for early Paleozoic tectonism in the Dadeldhura thrust sheet, far-west Nepal Himalaya. *Journal of Asian Earth Sciences*, *28*(4-6), 385-408.

Gehrels, G. (2014). Detrital zircon U-Pb geochronology applied to tectonics. *Annual Review of Earth and Planetary Sciences*, *42*, 127-149.

Kennedy, A. K., Kamo, S. L., Nasdala, L., & Timms, N. E. (2010). Grenville skarn titanite: potential reference material for SIMS U–Th–Pb analysis. *The Canadian Mineralogist*, *48*(6), 1423-1443.

Ludwig, K. R. (1998). Using Isoplot/Ex Version 1.00. *Berkeley Geochronological Center. Special Publ*, *1*, 43.

Ludwig, K. R. (2012). User's Manual for Isoplot 3.70, Berkeley Geochronology Center, Special Publication no. 4.

McDowell, F. W., McIntosh, W. C., & Farley, K. A. (2005). A precise 40Ar–39Ar reference age for the Durango apatite (U–Th)/He and fission-track dating standard. Chemical Geology, 214(3-4), 249-263.

Paton, C., Hellstrom, J., Paul, B., Woodhead, J., & Hergt, J. (2011). Iolite: Freeware for the visualisation and processing of mass spectrometric data. *Journal of Analytical Atomic Spectrometry*, *26*(12), 2508-2518.

Petrus, J. A., & Kamber, B. S. (2012). VizualAge: A novel approach to laser ablation ICP-MS U-Pb geochronology data reduction. *Geostandards and Geoanalytical Research*, *36*(3), 247-270.

Pointon et al., 2012 M.A. Pointon, R.A. Cliff, D.M. Chew The provenance of Western Irish Namurian Basin sedimentary strata inferred using detrital zircon U–Pb LA-ICP-MS geochronology Geological Journal, 47 (1) (2012), pp. 77-98

Schmitz, M. D., & Bowring, S. A. (2001). U-Pb zircon and titanite systematics of the Fish Canyon Tuff: An assessment of high-precision U-Pb geochronology and its application to young volcanic rocks. *Geochimica et Cosmochimica Acta*, *65*(15), 2571-2587.

Schoene, B., & Bowring, S. A. (2006). U–Pb systematics of the McClure Mountain syenite: thermochronological constraints on the age of the 40 Ar/39 Ar standard MMhb. Contributions to Mineralogy and Petrology, 151(5), 615.

Spandler, C., Hammerli, J., Sha, P., Hilbert-Wolf, H., Hu, Y., Roberts, E., & Schmitz, M. (2016). MKED1: A new titanite standard for in situ analysis of Sm–Nd isotopes and U–Pb geochronology. *Chemical Geology*, *425*, 110-126.

Thomson, S. N., Gehrels, G. E., Ruiz, J., & Buchwaldt, R. (2012). Routine low-damage apatite U-Pb dating using laser ablation–multicollector–ICPMS. Geochemistry, Geophysics, Geosystems, 13(2).

Vermeesch, P. (2012). On the visualisation of detrital age distributions. *Chemical Geology*, *312*, 190-194.

Wiedenbeck, M. A. P. C., Alle, P., Corfu, F., Griffin, W. L., Meier, M., Oberli, F. V., Spiegel, W. (1995). Three natural zircon standards for U-Th-Pb, Lu-Hf, trace element and REE analyses. *Geostandards newsletter*, *19*(1), 1-23.

Zattin, M., Andreucci, B., Thomson, S. N., Reiners, P. W., Talarico, F. M. (2012). New constraints on the provenance of the ANDRILL AND-2A succession (western Ross Sea, Antarctica) from apatite triple dating. Geochemistry, Geophysics, Geosystems, 13(10).