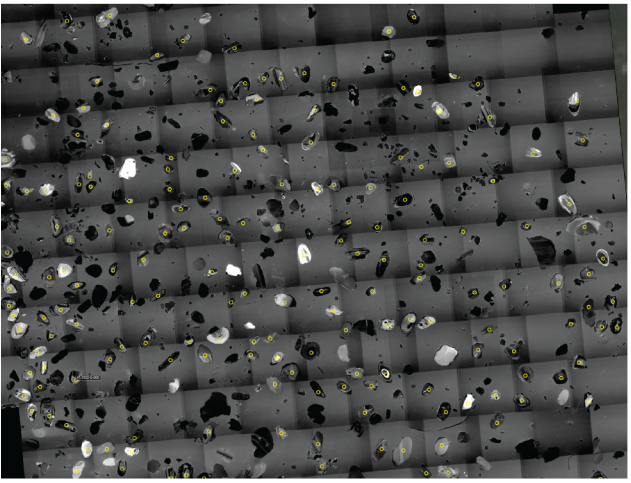
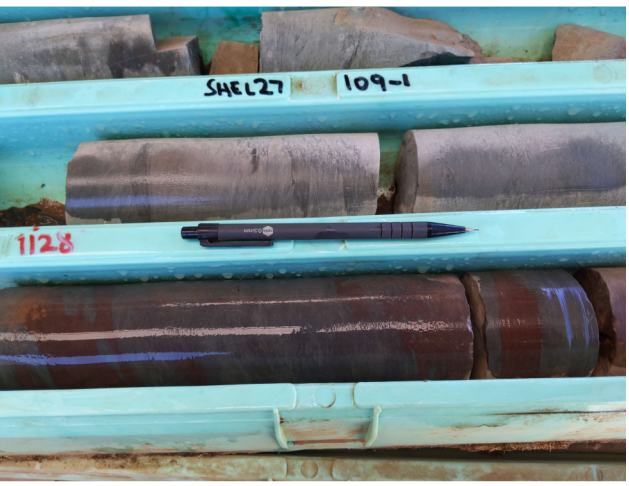
NORTHERN TERRITORY GEOLOGICAL SURVEY

RECORD 2023-003

Summary of results. NTGS geochronology project: Detrital zircon LA–ICP–MS U–Pb results from the Warburton and Pedirka basins









C Verdel, L Danyushevsky and I Belousov

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BIBLIOGRAPHIC REFERENCE: Verdel C, Danyushevsky L[1] and Belousov I[1], 2023. Summary of results. NTGS geochronology project: Detrital zircon LA–ICP–MS U–Pb results from the Warburton and Pedirka basins. *Northern Territory Geological Survey Record,* 2023-003.

(Record / Northern Territory Geological Survey ISSN 1443-1149)
ISBN: 978-0-7245-7410-0 (PDF)

Keywords: geochronology, laser ablation inductively-coupled plasma mass spectrometer, LA–ICP–MS, zircon, Northern Territory, Warburton Basin, Pedirka Basin, U–Pb.

Editor: GC MacDonald. Compilers: KJ Johnston, Marianne Fuller.

Northern Territory Geological Survey
3rd floor Paspalis Centrepoint Building
Smith Street Mall, Darwin
GPO Box 4550
Darwin NT 0801, Australia

Arid Zone Research Institute
South Stuart Highway, Alice Springs
PO Box 8760
Alice Springs NT 0871, Australia

For further information contact:
Minerals and Energy InfoCentre
Phone +61 8 8999 6443
Website: www.minerals.nt.gov.au/ntgs
Email: geoscience.info@nt.gov.au

[1] Centre for Ore Deposit and Earth Sciences, University of Tasmania, Hobart, TAS 7001, Australia

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Summary of results. NTGS geochronology project: Detrital zircon LA–ICP–MS U–Pb results from the Warburton and Pedirka basins

by
C Verdel, L Danyushevsky and I Belousov

SUMMARY

This Record presents laser ablation inductively–coupled plasma mass spectrometry (LA–ICP–MS) U–Pb isotope data and accompanying trace element data for detrital zircons from two sandstone samples of the Warburton Basin and one sandstone sample of the overlying Pedirka Basin. This study aims to constrain maximum depositional age, and the results will be included in a developing detrital zircon dataset for the Warburton and Pedirka basins in the southeast Northern Territory.

Detrital zircons from the samples described in this Record have U–Pb ages ranging from ca 3.4 Ga to ca 360 Ma. In all three samples, the major peak in detrital zircon age spectra occurs from ca 1.3 to 1 Ga, with a lesser peak from ca 700 to 500 Ma. These major age peaks are similar to those of many previously reported samples of Phanerozoic sandstone from the Amadeus Basin.

The youngest concordant zircon from undivided Warburton Basin sandstone in well SHEL27109-1 is ca 430 Ma, a result that, in conjunction with stratigraphic relationships, constrains the age of the uppermost Warburton Basin intersected by SHEL27109-1 to between Silurian and Carboniferous. A sample of early Permian sandstone of the Crown Point Formation from well McDills-1 contains no concordant zircons younger than Lower Mississippian, a result that is in strong contrast to Permian sandstones of eastern Australia, which are dominated by Permian zircons. This disparity is likely related to distance from the Permian arc system of eastern Australia.

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Appendix 2
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INTRODUCTION

This Record presents new U–Pb isotopic data and trace element data for detrital zircons from two samples of sandstone from the Warburton Basin and one sample from the Pedirka Basin (**Figure 1**). Zircon was analysed in order to constrain the timing of sedimentation and investigate zircon provenance. Results described herein are part of a larger project to develop a detrital zircon stratigraphy of the Warburton and Pedirka basins (Verdel *et al* 2021).

Sample locations are shown in **Figure 1**, and a summary of sample information is in **Table 1**. Full analytical data are listed in **Appendix 1**; zircon images are shown in **Appendix 2**.

The Warburton Basin (**Figure 1**) lies in the subsurface beneath parts of the Northern Territory, South Australia and Queensland. Strata of the Warburton Basin range from Cambrian to Devonian in age (eg Gatehouse 1986, Edgoose and Munson 2013). The Permian to Triassic Pedirka Basin (Munson and Ahmad 2013) of central Australia unconformably overlies the Cambrian to Devonian Warburton Basin. The early Permian Crown Point Formation of the Pedirka Basin immediately underlies the Purni Formation, which is the primary coal-bearing unit of the basin (Munson and Ahmad 2013).

ANALYTICAL PROCEDURES

U–Pb and trace element analyses were undertaken using LA–ICP–MS at the CODES Analytical Laboratories at the University of Tasmania in Hobart.

Mineral separation and mount preparation

Rock samples were crushed in a Cr-steel ring mill to a grain size <400 µm. Non-magnetic heavy minerals were separated using a gold pan and a Fe–B–Nd hand magnet. Zircons were handpicked from the heavy mineral concentrate. Selected grains were placed on double-sided sticky tape, and epoxy was poured into a 2.5 cm diameter mould on top of the zircons. The mount was dried and polished to expose mounted zircon grains using sandpaper and a polishing lap. The samples were then washed in distilled water in an ultrasonic bath.

Instrument setup and analysis

Zircon location and imaging

Zircon searches were performed on epoxy resin mounts coated with 20 nm of carbon using a FEI Quanta 600 SEM, equipped with an EDAX Genesis 7000 energy dispersive X-ray spectrometry (EDS) system and two Sapphire SUTW Si(Li) detectors at the Central Science Laboratory of the University of Tasmania. Cathodoluminescence (CL) images were collected on a FEI Quanta 600 SEM using a Gatan PanaCLF detector with a blue filter.

U–Pb isotope analysis

U–Pb analyses were performed with an ASI RESOlution S155 laser ablation system utilizing an ATL ATLEX I-LR Ar-F excimer laser operating at 193 nm and ~5 ns pulse width. The laser was coupled to an Agilent 7900 quadrupole ICP-MS. **Table 2** lists the operating and acquisition parameters. Downhole fractionation, instrument drift, and mass bias correction factors for Pb/U on zircons were calculated using the 91500 zircon reference material (Wiedenbeck *et al* 1995, Horstwood *et al* 2016). Accuracy of U–Pb ages was assessed using secondary zircon reference materials Plešovice (Sláma *et al* 2008) and Temora-2 (Black *et al* 2003a). These reference materials were analysed throughout each session under the same analytical conditions used for unknowns (**Table 3, Appendix 1**). Calibration of $^{207}Pb/^{206}Pb$ was done on the NIST610 reference glass, analysed with a 30 µm spot size throughout each analytical session, using the Pb isotopic compositions of Baker *et al* (2004). Each zircon analysis began with a 30 s blank gas measurement, followed by an additional 30 s of analysis time. Zircons were analysed with 20 µm spots with the laser at 5 Hz and a density of about 2 J/cm^2. A flow of He carrier gas at a rate of 0.35 l/min carried ablated particles out of the laser to be mixed with Ar gas and carried to the ICP.

Data reduction and presentation

U–Pb isotope data reduction was undertaken using the LADR program (Norris and Danyushevsky 2018). IsoplotR (Vermeesch 2018) was used for zircon age calculations. The difference between $^{207}Pb/^{206}Pb$ and $^{206}Pb/^{238}U$ ages was used to assess discordance. U–Pb ages of zircon grains with discordance >10% were not included in age spectra and were not used in estimates of maximum depositional age. All of the individual zircon U–Pb ages discussed are concordia ages (Ludwig 1998, Vermeesch 2021).

Table 1. Summary of sample information. Sample coordinates are referenced to the Map Grid of Australia 1994 (MGA94), Zone 53.

Sample ID	Collector	1:250 000 mapsheet	1:100 000 mapsheet	Province/ region	Easting (mE)	Northing (mN)	Formal name	Rock type	Mineral analysed
MC21CSV001	C Verdel	McDills	Etingambra	Warburton Basin	579398	7154077	Mereenie Sandstone	sandstone	zircon
HA21CSV001	C Verdel	Hale River	Simpson	Warburton Basin	602177	7258780	Undivided Warburton Basin	sandstone	zircon
MC21CSV005	C Verdel	McDills	Etingambra	Pedirka Basin	579398	7154077	Crown Point Formation	sandstone	zircon

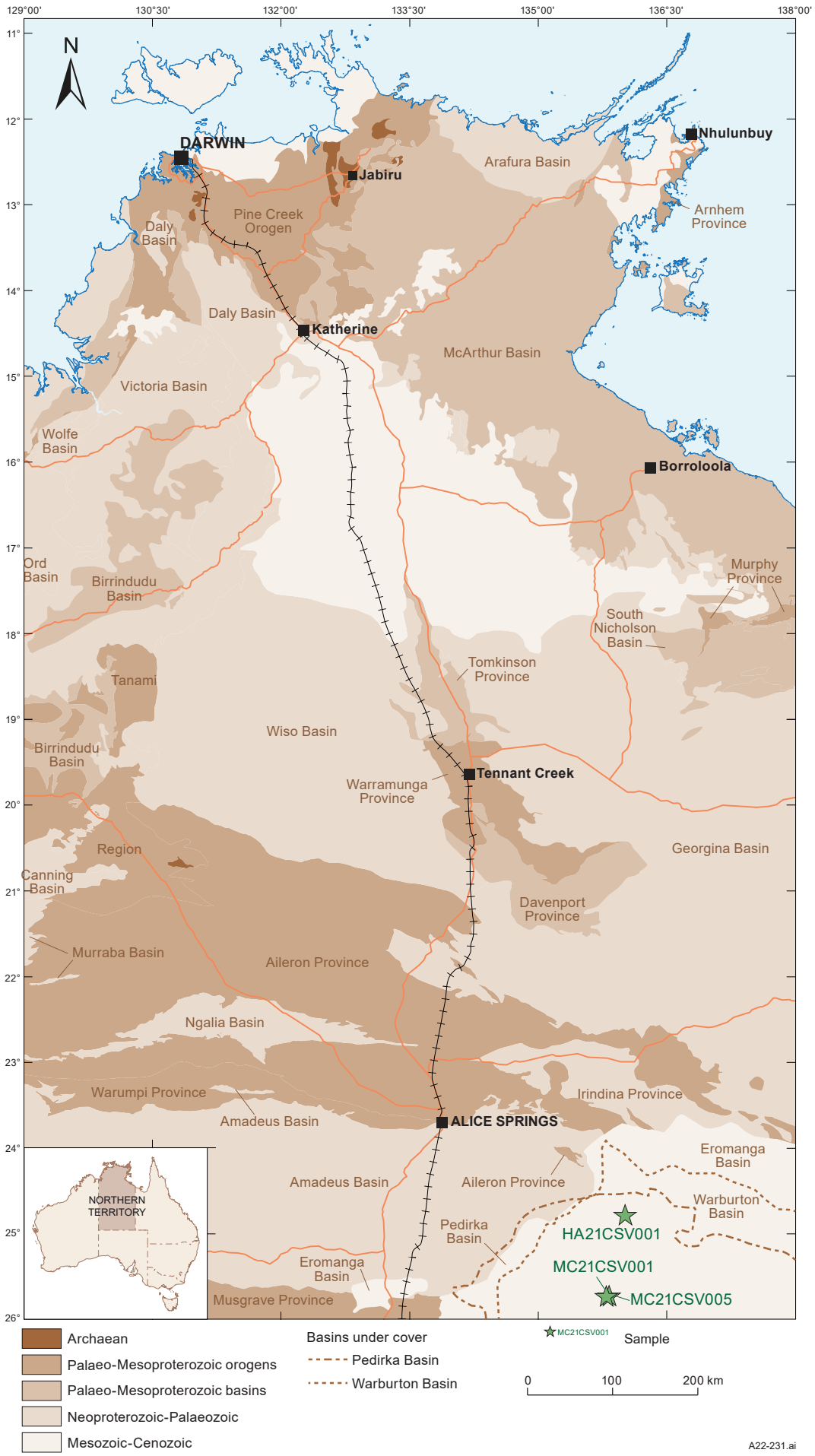

Figure 1. Location of detrital zircon samples from the Warburton and Pedirka basins. Sample HA21CSV001 is from well SHEL27109-1, and samples MC21CSV001 and MC21CSV005 are both from the McDills-1 well.

Table 2. LA–ICP–MS operating and data acquisition parameters.

Laser system	ATL ATLEX I-LR Ar-F eximer laser
Laser wavelength	193 nm
Laser mode	Spot Analysis
Nominal pulse width	c 5 ns
Repetition rate	5 Hz
Spot size (diamteter)	20 µm
Fluence	2 J/cm^2
Ablation cell	Resonetics S155
Ablation cell gas flow rate (He)	0.35 l/min
Tubing for gas flow	Nylon 6
laser beam focus	Fixed at sample surface
ICP-MS	Agilent 7900 quadrupole ICP-MS
Interface cones	Pt cones
Detector type	Electron Multiplier
Detector mode	pulse counting for U, Th and Pb isotopes
Detector vacuum	1.00E-05 Pa
Argon gas flow rate	l/min
Plasma	15 l/min
Auxiliary	0.8 l/min
Sample	1.05 l/min
RF Power	1350 W
Lenses (V)	
Extract 1	0.9 V
Extract 2	-90 V
Data acquisition and processing	
Isotopes measured (sampling time in parentheses)	^{31}P, ^{49}Ti, ^{56}Fe, ^{89}Y, ^{91}Zr, ^{93}Nb, ^{139}La, ^{140}Ce, ^{141}Pr, ^{146}Nd, ^{147}Sm, ^{153}Eu, ^{157}Gd, ^{159}Tb, ^{163}Dy, ^{165}Ho, ^{166}Er, ^{169}Tm, ^{172}Yb, ^{175}Lu, ^{178}Hf, ^{181}Ta, ^{202}Hg, ^{204}Pb, ^{206}Pb, ^{207}Pb, ^{208}Pb, ^{232}Th, ^{235}U and ^{238}U (0.26 s).
Samples per peak	1
Acquisition mode	peak jumping
Integration type	counts per second
Mass resolution	300
Oxide production rate	<0.15% ThO/Th
Analysis duration	80 s
Blank	30 s
Ablation	30 s
Washout	20 s

Table 3. Summary of geochronology results from zircon reference standards used in this study.

Reference material	**Reference**	**ID–TIMS Concordia Age (Ma)**	**±2σ**	**ID–TIMS ^{207}Pb/^{206}Pb Age (Ma)**	**±2σ**	**LA–ICP–MS ^{206}Pb/^{238}U Age (Ma)**	**±2σ**	**ID–TIMS ^{206}Pb/^{238}U Age (Ma)**	**±2σ**	**Number of measurements in this study**	**Weighted mean measured ^{207}Pb/^{206}Pb Age (Ma)**	**Uncertainty (2σ)**	**Relative standard deviation (%)**	**Weighted mean measured ^{206}Pb/^{238}U Age (Ma)**	**Uncertainty (2σ)**	**Relative standard deviation (%)**
91500 Zircon	Wiedenbeck *et al* 1995			1065.4	0.3			1062.4	0.4	32	1060.6	14.9	0.7	1063.5	2.7	0.1
Temora Zircon	Black *et al* 2003a and b	416.81	0.22					416.8	1.1	15	417.6	29.9	3.6	420.0	2.1	0.3
Plesovice Zircon	Aftalion *et al* 1989; Sláma *et al* 2008					338	1	337.13	0.37	15	320.9	16.6	2.6	342.5	1.5	0.2

SAMPLES ANALYSED

Mereenie Sandstone (MC21CSV001)

Sample information

NTGS Sample ID: MC21CSV001
Collector: C Verdel
1:250 000 mapsheet: MCDILLS (SG 53-07)
1:100 000 mapsheet: Etingambra (6046)
Region: Warburton Basin
Grid Reference: GDA94 Zone 53, 579398mE, 7154077mN
Formal name: Mereenie Sandstone
Lithology: medium-grained sandstone
Geochronology target: zircon

Interpreted age summary

Youngest single concordant zircon: 497±9 Ma (2σ).

Location details and lithological characteristics

Sample MC21CSV001 is a moderately sorted, medium-grained sandstone collected from a depth of 2322 m within the middle of the Mereenie Sandstone interval intersected by McDills-1 (**Figure 2**). Mereenie Sandstone occurs across a wide part of the Amadeus Basin (eg Prichard and Quinlan 1962, Edgoose 2013, Shillito and Davies 2021), and trace fossil evidence suggests that deposition of Mereenie Sandstone occurred from Silurian to Devonian time (Gouramanis and McLoughlin 2016).

In the Warburton Basin, which lies to the east of the Amadeus Basin, Mereenie Sandstone has only been identified in the McDills-1 well (Amerada Petroleum 1965, Edgoose and Munson 2013). In McDills-1, Mereenie Sandstone is overlain by the Upper Devonian to Carboniferous Polly Conglomerate, and is underlain by unnamed siliciclastic rocks that contain detrital zircons as young as ca 500 Ma (Verdel *et al* 2021). The Mereenie Sandstone interval in McDills-1 consists of red to reddish orange, fine- to coarse-grained, cross-stratified sandstone and lesser shale (Amerada Petroleum 1965).

Analytical information

Analyst: Maxwell Morissette
Acquisition Date: 11 May 2022

U–Pb isotopic results

U–Pb geochronology data were collected from 202 zircons (**Figures 4**, **5**; **Appendix 1**). Ages from 52 zircons are >10% discordant (**Figure 4**), so these analyses are excluded from further interpretation (**Appendix 1**). The remaining 150 zircons have U–Pb ages ranging from ca 3390 Ma to ca 500 Ma (**Figure 5**). The main clusters of ages occur in the intervals of ca 3000 to 2500 Ma, ca 1700 to 1400 Ma, ca 1250 to 800 Ma, and ca 650 to 500 Ma. The youngest individual concordant zircon has a U–Pb age of 497±9 Ma (2σ).

Interpretation

The youngest individual concordant zircon from sample MC21CSV001 is tens of millions of years older than the depositional age of Mereenie Sandstone (eg Gouramanis and McLoughlin 2016). The main population of ca 1100 Ma zircons in the sample is sourced from rocks that are likely associated in some way with the Musgrave Province of central Australia (eg Haines *et al* 2016). The subsidiary population of ca 650 to 500 Ma zircons is the 'Pacific-Gondwana' zircon population, which is widespread in Phanerozoic sandstone of Australia (eg Ireland *et al* 1998, Purdy *et al* 2016).



Figure 2. Mereenie Sandstone collected from a depth of 2322 m in McDills-1 (sample MC21CSV001). Pen is 14 cm long.

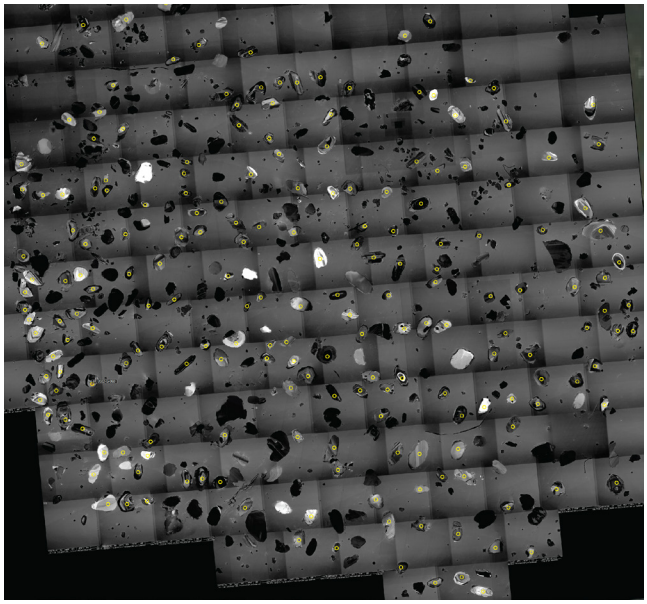

Figure 3. Representative CL images of zircon from the Mereenie Sandstone sample MC21CSV001. All CL images are shown in **Appendix 2**.

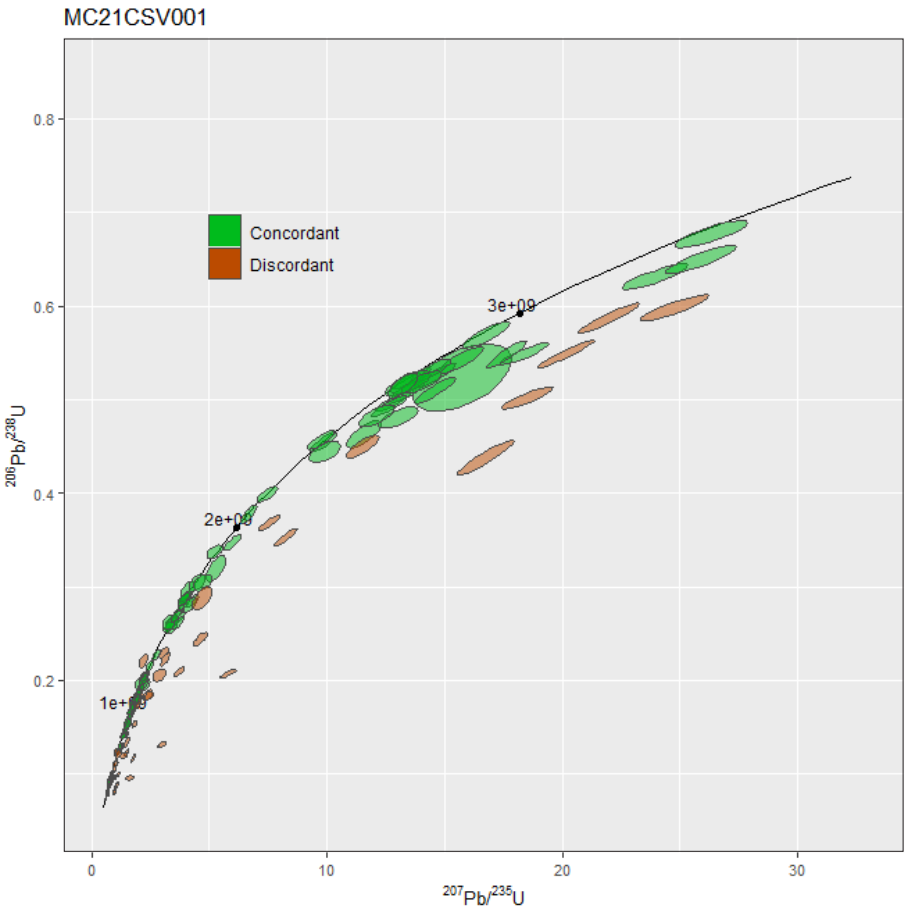

Figure 4. Concordia diagram of zircon analyses from Mereenie Sandstone in McDills-1 (MC21CSV001). Green ellipses are concordant or near-concordant analyses (n=150). Red ellipses are >10% discordant (n=52).

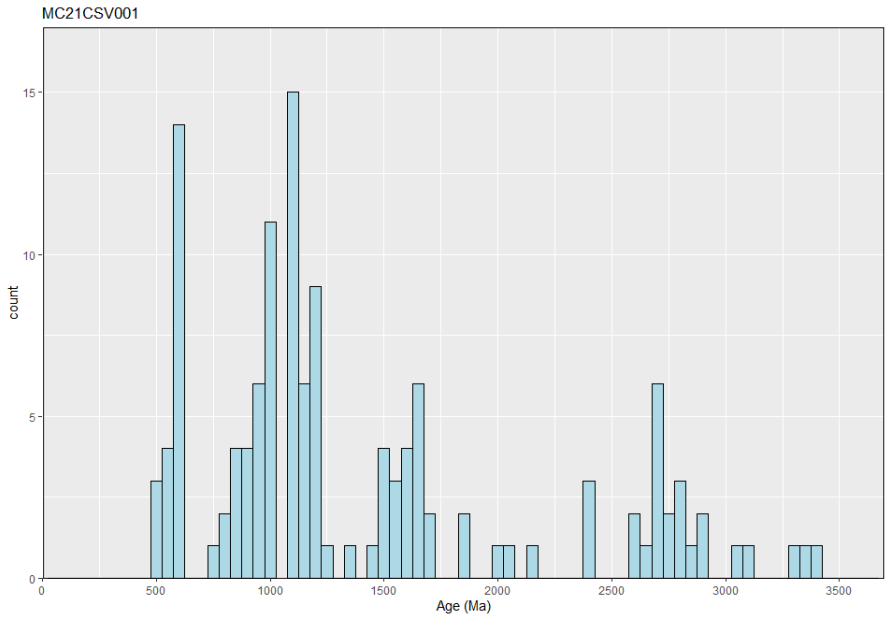

Figure 5. Histogram of <10% discordant zircon U–Pb concordia ages from Mereenie Sandstone in McDills-1 (MC21CSV001; n=150). Bin width is 50 My.

Undivided Warburton Basin sandstone (HA21CSV001)

Sample information

NTGS Sample ID: HA21CSV001
Collector: C Verdel
1:250 000 mapsheet: HALE RIVER (SG 53-03)
1:100 000 mapsheet: SIMPSON (6148)
Region: Warburton Basin
Grid Reference: GDA94 Zone 53, 602177mE, 7258780mN
Formal name: undivided Warburton Basin
Lithology: fine-grained sandstone
Geochronology target: zircon

Interpreted age summary

Youngest single concordant zircon: 428±8 Ma (2σ).

Location details and lithological characteristics

The SHEL27109-1 well, located in the western part of the Warburton Basin, intersected ~2.6 m of undivided Warburton Basin sandstone. The sandstone occurs at the base of the well beneath Permian siliciclastic strata of the Crown Point Formation (Merlin Coal Pty Ltd 2011). Sample HA21CSV001 is a well-sorted, fine-grained sandstone from a depth of 1128 m within the 'undivided Warburton Basin' interval of SHEL27109-1 (**Figure 6**).

Analytical information

Analyst: Maxwell Morissette
Acquisition Date: 11 May 2022

U–Pb isotopic results

U–Pb geochronology data were collected from 201 zircons (**Figures 8**, **9**; **Appendix 1**). Results from 82 zircons are >10% discordant (**Figure 8**), so these analyses are excluded from further interpretation (**Appendix 1**). The remaining 119 zircons have U–Pb ages ranging from ca 3320 Ma to ca 430 Ma (**Figure 9**). The main clusters of ages occur in the intervals of ca 1900 to 1500 Ma, ca 1300 to 900 Ma, and ca 700 to 450 Ma. The youngest concordant zircon U–Pb age is 428±8 Ma (2σ).

Interpretation

The undivided Warburton Basin sandstone at the base of SHEL27109-1 is older than Permian based on stratigraphic relationships with the overlying Crown Point Formation. The youngest concordant zircon (ca 428 Ma) from sample HA21CSV001 therefore places an important maximum constraint on depositional age. Two other zircons from the sample are also in the Ordovician to Silurian interval (ca 455 Ma and 432 Ma). Carboniferous strata are largely or entirely absent in the Warburton and Pedirka basins region, so it is most likely that the undivided Warburton Basin sandstone of SHEL27109-1 is Silurian to Devonian in age, broadly the same age as Mereenie Sandstone of the Amadeus Basin and western Warburton Basin in McDills-1 (eg Edgoose 2013, Edgoose and Munson 2013; **Figure 2**).



Figure 6. Fine-grained sandstone of the undivided Warburton Basin from a depth of 1128 m in SHEL27109-1 (sample HA21CSV001). Pencil is 14 cm long.

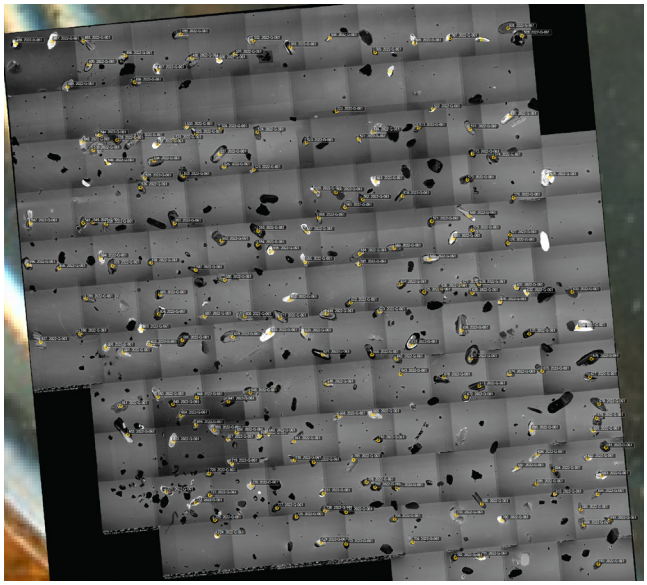

Figure 7. Representative CL images of zircon from the undivided Warburton Basin sample HA21CSV001. All CL images are shown in **Appendix 2**.

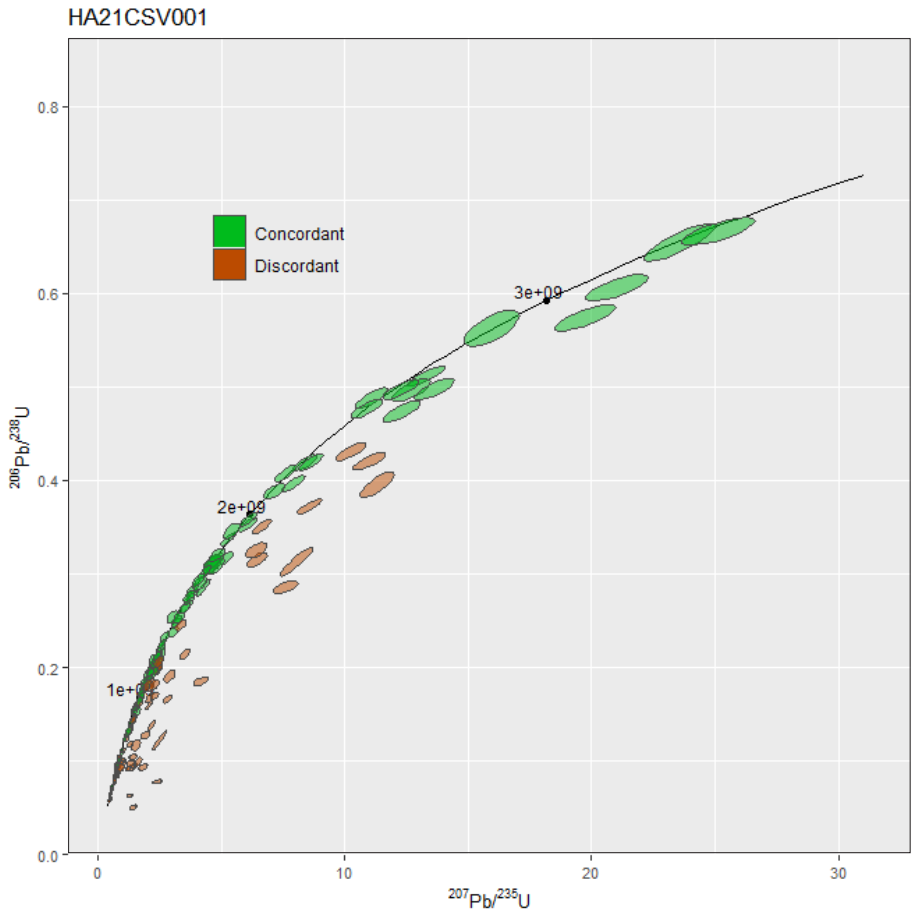

Figure 8. Concordia diagram of zircon analyses from undivided sandstone of the Warburton Basin in SHEL27109-1 (HA21CSV001). Green ellipses are concordant or near-concordant analyses (n=119). Red ellipses are >10% discordant (n=82).

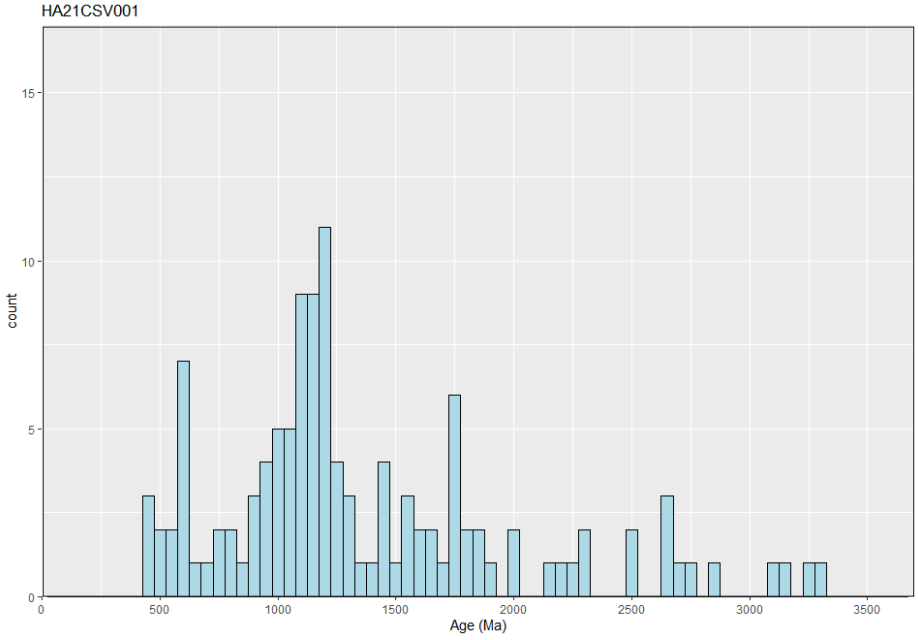

Figure 9. Histogram of <10% discordant zircon U–Pb concordia ages from undivided sandstone of the Warburton Basin in SHEL27109-1 (HA21CSV001; n=119). Bin width is 50 My.

Crown Point Formation (MC21CSV005)

Sample information

NTGS Sample ID: MC21CSV005
Collector: C Verdel
1:250 000 mapsheet: MCDILLS (SG 53-07)
1:100 000 mapsheet: ETINGAMBRA (6046)
Region: Pedirka Basin
Grid Reference: GDA94 Zone 53, 579398mE, 7154077mN
Formal name: Crown Point Formation
Lithology: medium- to coarse-grained sandstone
Geochronology target: zircon

Interpreted age summary

Youngest single concordant zircon: 358±6 Ma (2σ).

Location details and lithological characteristics

The McDills-1 well in the western part of the Northern Territory Warburton Basin intersected ~190 m of sandstone of the Crown Point Formation of the Pedirka Basin (Doig and Jarrett, 2021). Detrital zircon sample MC21CSV005 is medium- to coarse-grained sandstone from a depth of 820 m in McDills-1 (**Figure 10**), which is in the middle part of the Crown Point Formation according to the revised stratigraphy of Doig and Jarrett (2021).

Analytical information

Analyst: Maxwell Morissette
Acquisition Date: 11 May 2022

U–Pb isotopic results

U–Pb geochronology data were collected from 202 zircons (**Figures 12**, **13**; **Appendix 1**). Ages from 79 zircons are >10% discordant (**Figure 12**), so these analyses are excluded from further interpretation (**Appendix 1**). The remaining 123 zircons have U–Pb ages ranging from ca 3360 Ma to ca 360 Ma (**Figure 13**). The main clusters of ages occur in the intervals of ca 1800 to 1400 Ma, ca 1300 to 800 Ma, and ca 650 to 450 Ma. The youngest concordant zircon U–Pb age is 358±6 Ma (2σ).

Interpretation

Based on palynological evidence, the Crown Point Formation is no younger than Asselian (ca 294 Ma; Munson and Ahmad 2013); therefore, even the single youngest concordant zircon from sample MC21CSV005 is about 60 My older than the depositional age. In contrast, early Permian sandstones of eastern Australia are dominated by Permian to Carboniferous zircons that closely approximate depositional age (Campbell *et al* 2015, Phillips *et al* 2018). A likely explanation for this disparity in detrital zircon age populations in sedimentary rocks of roughly the same age is their different proximity to the Permian arc system of eastern Australia (eg Campbell *et al* 2020).



Figure 10. Sandstone of the Crown Point Formation from a depth of 820 m in McDills-1 (sample MC21CSV005). Pencil is 14 cm long.

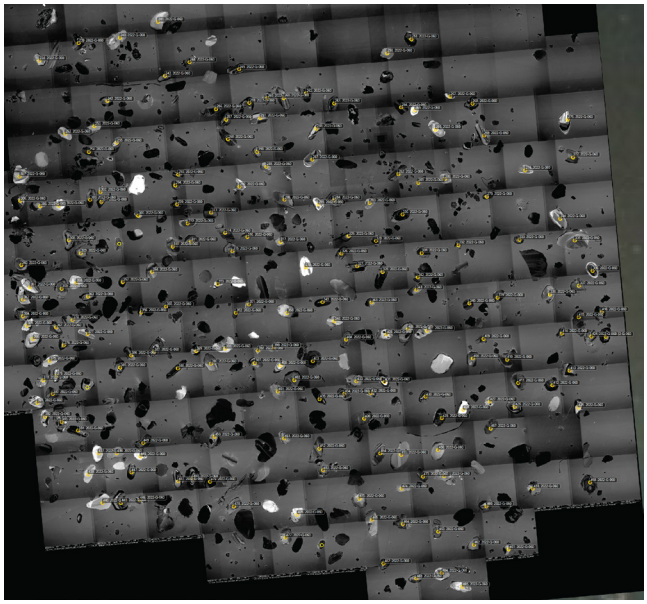

Figure 11. Representative CL images of zircon from the Crown Point Formation sample MC21CSV005. All CL images are shown in **Appendix 2**

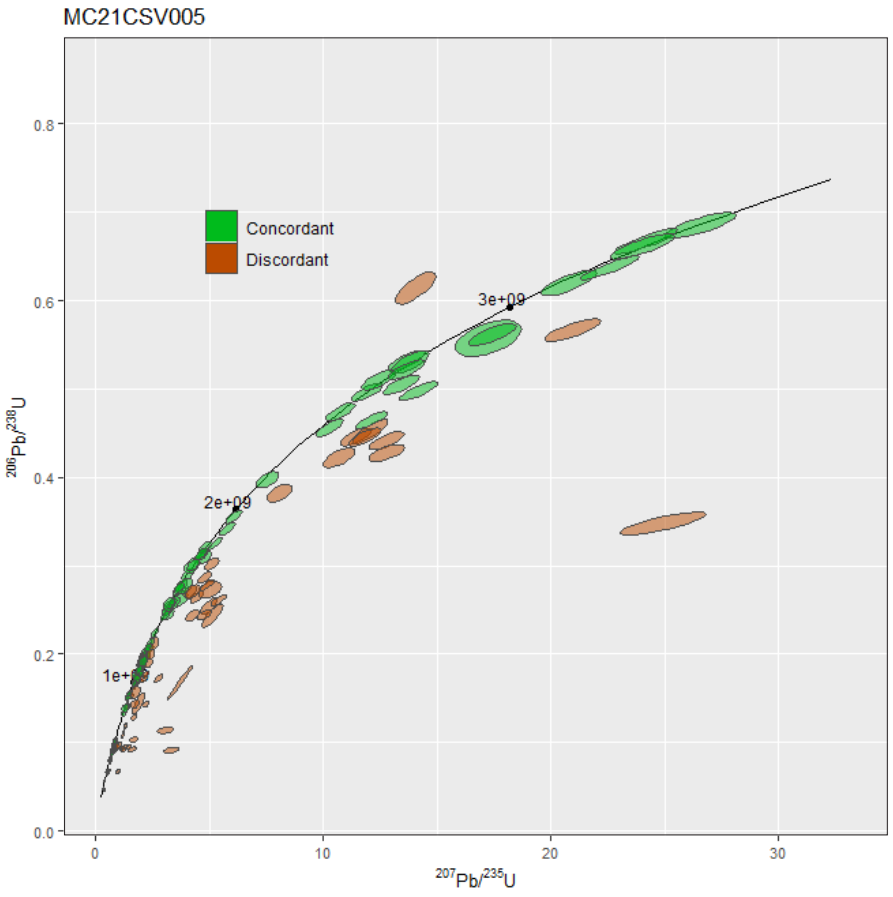

Figure 12. Concordia diagram of zircon analyses from Crown Point Formation in McDills-1 (MC21CSV005). Green ellipses are concordant or near-concordant analyses (n=123). Red ellipses are >10% discordant (n=79).

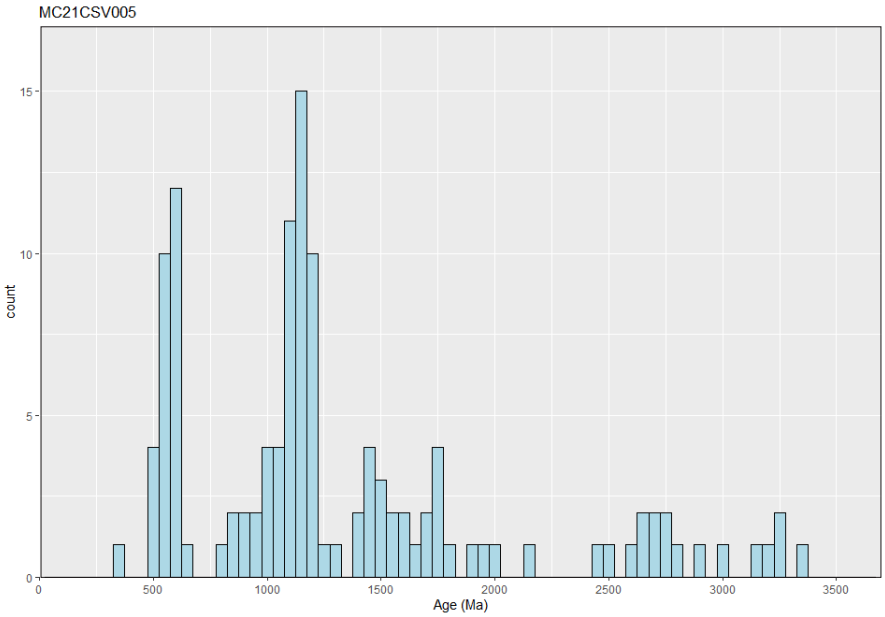

Figure 13. Histogram of <10% discordant zircon U–Pb concordia ages from Crown Point Formation in McDills-1 (MC21CSV005; n=123). Bin width is 50 My.

DETRITAL ZIRCON PETROCHRONOLOGY

Like Hf isotope ratio, the long-term secular records of some zircon trace element concentrations are associated with tectonomagmatic processes (eg Balica *et al* 2020, Verdel *et al* 2021). Zircon Yb/U, in particular, seems to follow the same basic temporal pattern as zircon Hf isotope ratio (Grimes *et al* 2007, Verdel *et al* 2021). Concordant zircons from the three samples discussed herein were combined to create a detrital zircon Yb/U record for the Warburton and Pedirka basins (**Figure 14**).

Three features of the resulting record are noteworthy. The first is the rise in Yb/U from ca 2000 Ma to 1400 Ma (**Figure 14**). Part of this Palaeoproterozoic to Mesoproterozoic rise coincides with the ca 1640 Ma Liebig Orogeny of central Australia (**Figure 14**, Scrimgeour *et al* 2005), which also marks a shift in zircon Hf isotope composition to more radiogenic values immediately following the orogeny (Hollis *et al* 2013, Haines *et al* 2016). Some of the highest zircon Yb/U in the Warburton and Pedirka basins dataset are in the range of ca 1500 to 1400 Ma (**Figure 14**), a period of particularly radiogenic zircon Hf isotope composition in the Musgrave Province that may signify the formation of a magmatic arc (eg Wade *et al* 2006, Smits *et al* 2014, Haines *et al* 2016, Verdel *et al* 2021). The second noteworthy feature of the detrital zircon Yb/U record is the subsequent decline in Yb/U from ca 1400 to 1250 Ma (**Figure 14**). This decline is mimicked by the trend of zircon Hf isotope composition in the Musgrave Province, which reflects additions of continental crust that might be associated with processes such as ocean closure and continental collision (eg Smits *et al* 2014).

The third and final noteworthy feature is the zircon Yb/U minimum at ca 575 Ma (**Figure 14**), a period during which zircon Hf isotope composition reached a minimum globally (eg Keller *et al* 2019). Given that this zircon population seems to have a source outside Australia (eg Morón *et al* 2019), the geochemical composition of Warburton and Pedirka basin detrital zircons of this age do not reflect tectonic or magmatic processes that occurred in central Australia. The extremely 'reworked' compositions of zircons from this period are likely related to the formation of Gondwana (eg Fritz *et al* 2013, Verdel *et al* 2020).

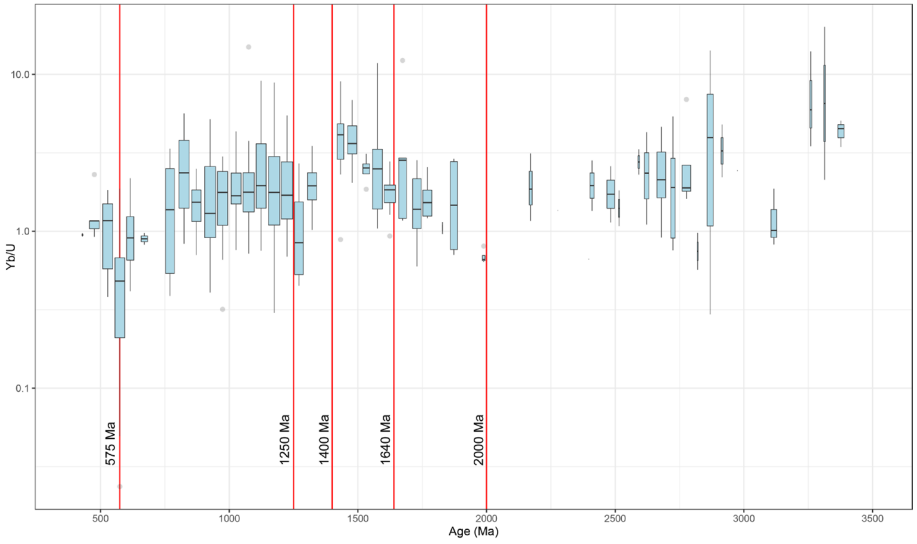

Figure 14. Zircon Yb/U record of concordant detrital zircons from samples described in this Record. Bin width is 50 My.

ACKNOWLEDGEMENTS

We thank Elliot Foley and Jo Whelan for their constructive reviews.

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