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# 1 **Neoproterozoic Geochronology and Provenance of the** 2 **Adelaide Superbasin**

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## 13 **Short Title**

14 Adelaide Superbasin geochronology and provenance

## 15 **Abstract**

16 The Adelaide Superbasin (Adelaide Rift Complex, Stuart Shelf, Torrens Hinge Zone,  
17 Coomalarnie Platform, and Cambrian Stansbury and Arrowie Basins) is a vast sedimentary  
18 basin in southern Australia that initiated due to the break-up of central Rodinia and, evolved  
19 into the Australian passive margin on edge of the Pacific Basin. Rocks within it contain  
20 evidence for the evolving earth system through the Neoproterozoic, including type sections of  
21 the Ediacaran fauna, Sturtian and Marinoan glaciations, and the GSSP for the base of the  
22 Ediacaran period. Much research over the last century has unravelled the lithostratigraphy and  
23 sedimentology of the basin. Despite this, the rocks are poorly dated, and their sedimentary  
24 provenance and link with tectonic geography is poorly known. This poor chronology hampers  
25 global and local efforts to gain a detailed understanding and chronological framework of the  
26 interplay between tectonics and momentous changes to the earth system during this time.  
27 This paper presents a comprehensive database of detrital zircon geochronology and review of



28 geochronology for the Neoproterozoic of the Adelaide Superbasin, highlighting the  
29 stratigraphic, and spatial locations of available data.

30 In the north of the basin, zircons were sourced locally in the initial stages of rifting, ca. 830  
31 Ma—from the adjacent Gawler Craton and Curnamona Province. During the late Tonian,  
32 detritus was transported along graben from the north-west, from the Musgrave Orogen, as the  
33 rift basin developed during the opening of the nascent Pacific Ocean. Cryogenian icesheets  
34 punctuate the detrital record with an ephemeral return to more localised rift shoulder sources.  
35 In the Ediacaran, there is an increasing influence of younger (<740 Ma) detrital zircon from an  
36 enigmatic source that we interpret to be from southern (i.e. Antarctic) sources, with a  
37 corresponding shift in the late Mesoproterozoic age peaks, from ca. 1180 Ma to ca. 1090 Ma,  
38 and corresponding decrease in older, ca. 1600 Ma, detritus. These changes in sediment source  
39 reflect the changing tectonic geography and large-scale environmental influence of the  
40 Cryogenian glaciations as the basin evolved from a local rift, to a larger rift basin and finally to  
41 a continental margin, with sedimentary input becoming increasingly restricted over time.

#### 42 **Keywords:**

43 Adelaide Superbasin; Adelaide Geosyncline; Adelaide Fold Belt; detrital zircon; Adelaide Rift  
44 Complex; Neoproterozoic

#### 45 **1. Introduction**

46 The Neoproterozoic, particularly during the transition from Rodinia to Gondwana, is a pivotal time in Earth's  
47 history. The reconfiguration of the continental plates coincided with climatic extremes; near-global  
48 glaciations, a significant and stable rise in atmospheric oxygen levels, and the proliferation of eukaryotic and  
49 metazoan life (Bao et al. 2008; Brasier & Lindsay 2001; Brocks 2018; Brocks et al. 2017; Campbell & Squire  
50 2010; Cox et al. 2016; Gernon et al. 2016; Halverson et al. 2009; Hoffman et al. 2017; Hoffman & Li 2009;  
51 Kasemann et al. 2005; Knoll & Carroll 1999; Knoll & Walter 1992; Maruyama & Santosh 2008; Meert &  
52 Lieberman 2008; Santosh 2010; Schmidt & Williams 1995; Squire et al. 2006; Ward et al. 2019). Much of  
53 the evidence for these events has been reported from rocks within the Adelaide Superbasin, such as key



54 sequences of the Cryogenian global glaciations (Le Heron et al. 2011; Rose et al. 2013), Ediacaran Acraman  
55 bolide ejecta layer (Williams 1986; Williams & Gostin 2005), the eponymous Ediacaran fauna (Gehling &  
56 Droser 2012; Sprigg 1948) and the global boundary stratotype section and point (GSSP) for the base of the  
57 Ediacaran (Knoll et al. 2006). Yet, our knowledge of the chronology and tectonic evolution of the region is  
58 presently a hindrance to the calibration of other investigative techniques like chemostratigraphy, and the  
59 development of time and global correlation frameworks for all of these earth system events and stratigraphic  
60 sequences. While much work has been done to this end around the globe, particularly in Canada (Leslie  
61 2009; Milton et al. 2017), China (Condon et al. 2005; Rooney et al. 2020), Svalbard (Halverson et al. 2018),  
62 Namibia (Lamothe et al. 2019; Miller 2013; Nascimento et al. 2017), and Scotland (Dempster et al. 2002;  
63 MacLennan et al. 2018; Noble et al. 1996), geochronology of the Neoproterozoic sequences remains a  
64 significant challenge due to the fragmented, eroded, and commonly deformed stratigraphic record for the  
65 Neoproterozoic (Halverson et al. 2018; MacLennan et al. 2018). Here we review and present new data for the  
66 geochronology of arguably the most complete Neoproterozoic basin in the world, the Adelaide Superbasin  
67 [Figure 1, Figure 3].





68  
69 **Figure 1** – General location map of the Neoproterozoic component of the Adelaide Superbasin (purple solid outline), with geographic  
70 regions (white outlines) and names used in this publication. **PDR**: Peake and Denison Ranges; **WR**: Willouran Ranges; **NFR**: North  
71 Flinders Ranges; **SFR**: South Flinders Ranges; **NMLR**: North Mount Lofty Ranges; **SMLR**: South Mount Lofty Ranges; **NA**: Nackara Arc;  
72 **BR**: Barrier Ranges; **KB**: Koonenberry Belt. Base map is a (false) colour shade overlain by a hill shade DEM image generated from  
73 publicly available shuttle radar topography mission (SRTM) data from NASA. For geological subdivisions of the Adelaide Superbasin the  
74 reader is referred to Figure 3.

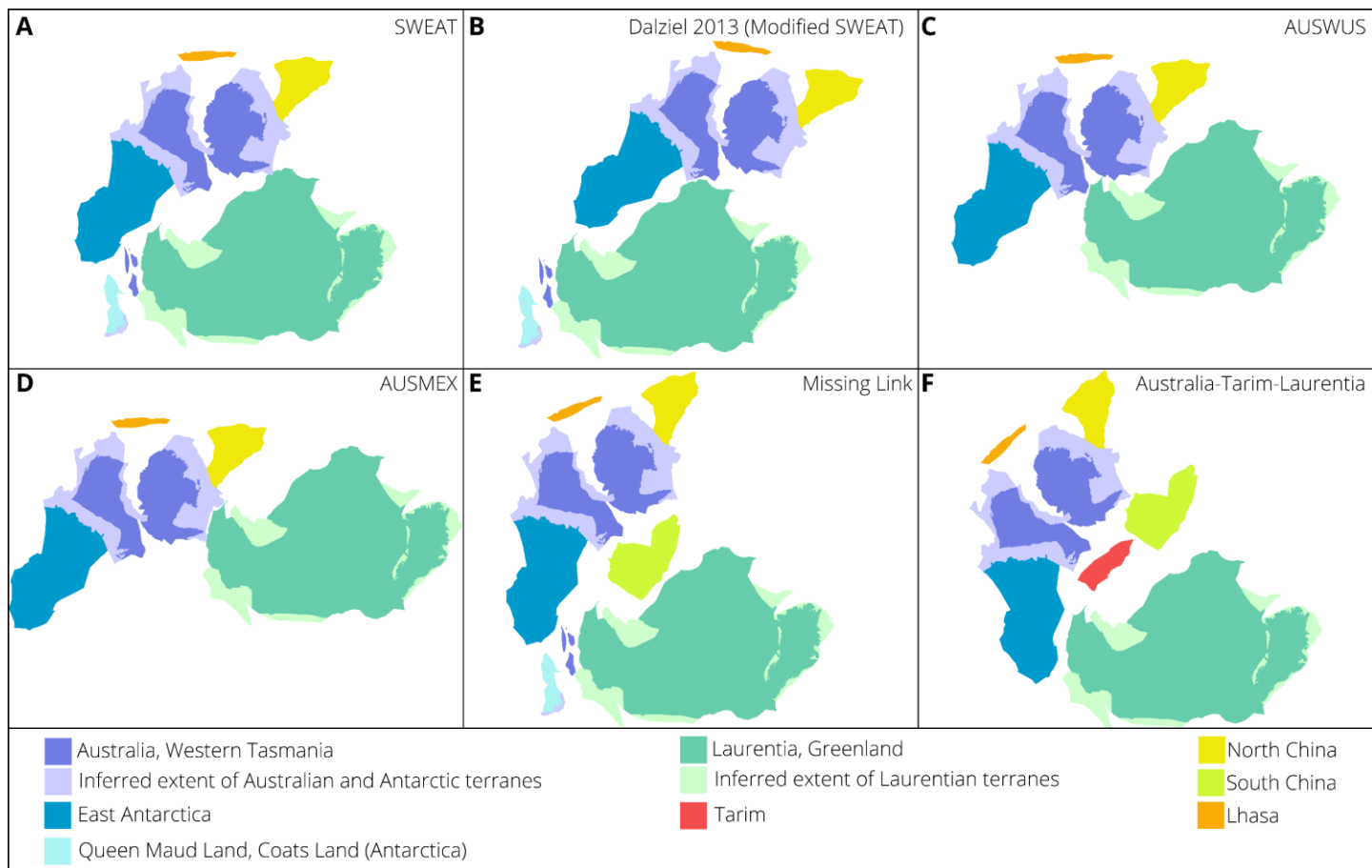
75 This paper presents new detrital zircon U–Pb data and summarises previously published detrital zircon  
76 geochronological data from the Neoproterozoic of the Adelaide Superbasin. The intention is to highlight  
77 current data, present new data, and identify gaps in the geochronology of the Neoproterozoic of the Adelaide  
78 Superbasin. This work will form the basis of ongoing research to develop a detailed chronostratigraphic and  
79 sedimentary provenance framework of the Neoproterozoic portion of the Adelaide Superbasin, with aims to  
80 explore the evolving tectonic geography of the Adelaide Superbasin and the nascent Pacific Basin.

## 81 **2. Background**

### 82 *2.1. Australia and Laurentia in Rodinia*

83 Though much contention still exists about the configuration of Rodinia, it is widely accepted that Australia-

84 East Antarctica were attached to the western margin of Laurentia in Rodinia (Merdith et al. (2017a) and  
 85 references therein). There are currently five proposed models [Figure 2]: South-West United States – East  
 86 Antarctica (SWEAT—Dalziel 1991; Hoffman 1991; Moores 1991), Australia-Western United States  
 87 (AUSWUS—Brookfield 1993; Karlstrom et al. 1999), Australia-Mexico (AUSMEX—Wingate et al. 2002), and  
 88 Missing-Link (Australia-South China-Laurentia; Li et al. 2008; Li et al. 1995), or Australia-Tarim-Laurentia  
 89 (Wen et al. 2017; Wen et al. 2018). In all five models, authors pair Australia-East Antarctica with Laurentia;  
 90 however, they differ in the position of Australia-East Antarctica relative to Laurentia.



91  
 92 **Figure 2** – Reconstructions of Rodinia **(A)** South-West United States-East Antarctica (SWEAT) (Dalziel 1991; Hoffman 1991; Moores  
 93 1991); **(B)** Modified SWEAT (Dalziel 2013) ; **(C)** Australia-Western United States (AUSWUS) (Brookfield 1993; Karlstrom et al. 1999); **(D)**  
 94 Australia-Mexico (AUSMEX) (Wingate et al. 2002); **(E)** Australia-South China-Laurentia (Missing Link) (Li et al. 2008; Li et al. 1995); **(F)**  
 95 Australia-Tarim-Laurentia (Wen et al. 2017; Wen et al. 2018). Original SWEAT configuration based on the GPlates model of Mulder et al.  
 96 (2020). Positions and rotations of continental blocks are relative to a fixed Laurentia.

97 The timing of the Rodinia continental breakup has also been contentious, with suggestions ranging from  
 98 before ca. 750 Ma (Li & Powell 2001; Mulder et al. 2020; Wingate & Giddings 2000), ca. 700 Ma (Powell et al.  
 99 1994; Preiss 2000); ca. 600 Ma (Direen & Crawford 2003) through to ca. 540 Ma (Veevers et al. 1997).

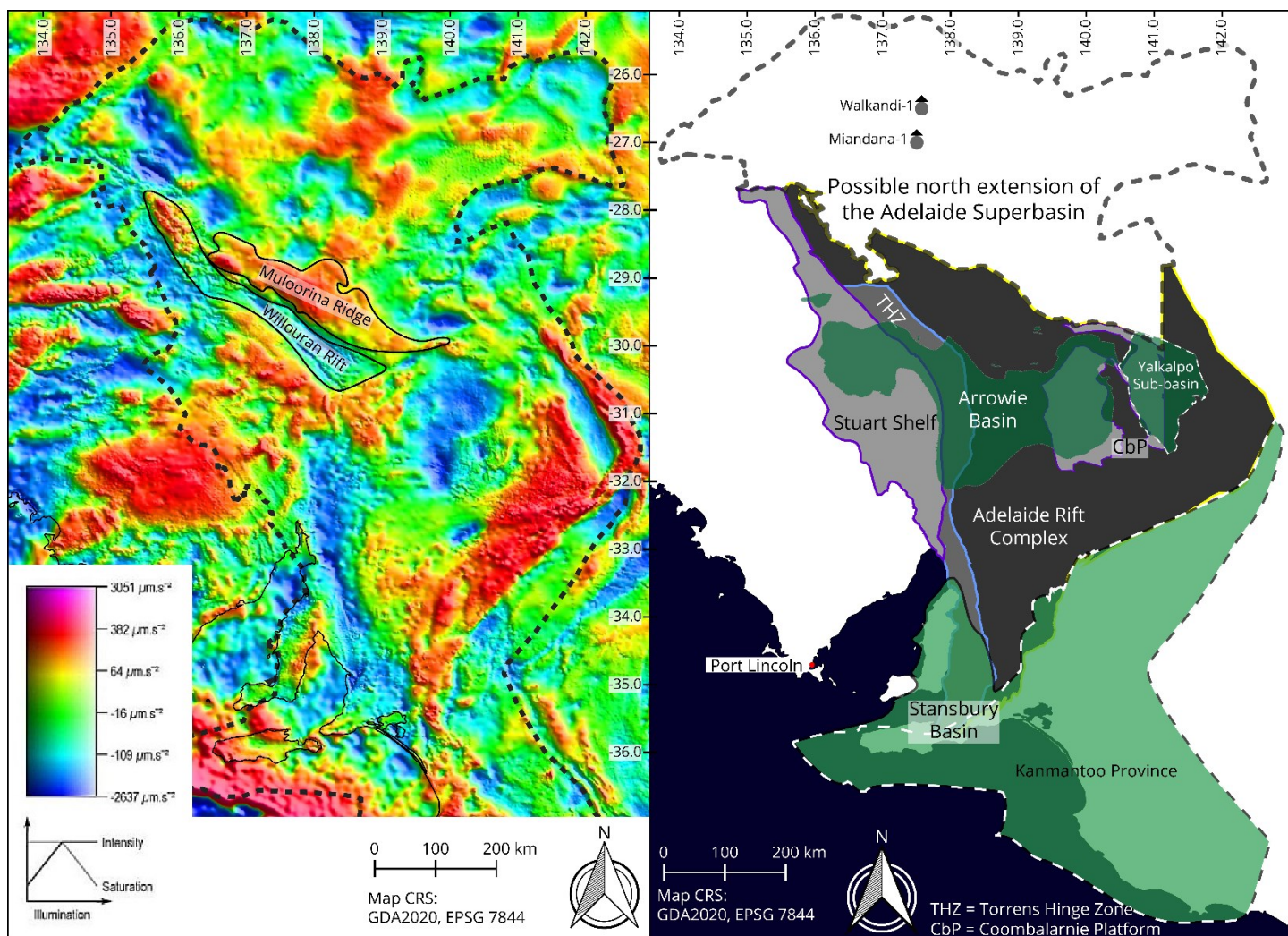
100 Merdith et al. (2017b), recently investigated the kinematic implications of these configurations and timings

101 and concluded that breakup must have occurred before ca. 725 Ma to develop the geography of Palaeozoic  
102 Gondwana. Merdith et al. (2017b) also concluded that a missing-link configuration was unlikely based on the  
103 plate kinematic considerations (see also Cawood et al. 2020).

## 104 2.2. *The Adelaide Superbasin and the Adelaide Rift Complex*

### 105 2.2.1. *Basin Hierarchy and Historical Chronostratigraphy*

106 Previously termed the Adelaide Geosyncline (Mawson & Sprigg 1950), the Adelaide Superbasin (Preiss 2000;  
107 Preiss et al. 2002) is a large Neoproterozoic to middle Cambrian sedimentary system at the south-eastern  
108 margin of Proterozoic Australia (Boger 2011; Cawood 2005; Cawood & Korsch 2008; Direen & Crawford  
109 2003; Li & Powell 2001; Myers et al. 1996; Preiss 2000; Walter & Veevers 1997). It is akin to the Centralian  
110 Superbasin (Munson et al. 2013; Walter & Veevers 1997) regarding age and hierarchy, i.e. containing large  
111 scale (up to ~1000 km length) named basins and sub-basins. The central Adelaide Superbasin is here named  
112 to include the rocks of the Adelaide Rift Complex (ARC), the contiguous undeformed rocks of the Torrens  
113 Hinge Zone, the Stuart Shelf (Sprigg 1952), and Coombalarnie Platform (Callen 1990). It also includes the  
114 Cambrian Arrowie and Stansbury Basins (Dalgarno 1964; Wopfner 1972). The Arrowie Basin includes  
115 Yalkalpo Sub-basin (Callen 1990), and the Stansbury Basin includes the Kanmantoo Trough/Province [Figure  
116 3]. Pending formal redefinition, we suggest that the Adelaide Superbasin is an appropriate name for the  
117 whole sequence of Neoproterozoic to middle Cambrian rocks of south-east Proterozoic/Palaeozoic Australia  
118 with the name "Adelaide Rift Complex" restricted for the series of Neoproterozoic rift-passive margin basins,  
119 with which this paper is concerned. This change alleviates confusion and pays respect to the historical  
120 naming (Preiss 2000; Sprigg 1952), whilst updating it to suit modern tectonic theory. As such, further  
121 reference to the Adelaide Rift Complex (ARC) specifically refers to the Neoproterozoic basin and not the  
122 entire Adelaide Superbasin.



123  
 124 **Figure 3 – [Left]** Gravity anomaly hue-saturation-intensity (HSI) image showing the Muloorina Ridge, Willouran Rift and outline of the  
 125 Adelaide Superbasin. (Gravity data from Geoscience Australia WMS server). **[Right]** The Adelaide Superbasin and its constituent  
 126 components. Grey shades represent the Neoproterozoic components and green shades represent the Cambrian components. The  
 127 Kanmantoo Province is a subdivision of the Stansbury Basin, and the Yalkalpo Sub-basin is a subdivision of the Arrowie Basin, both are  
 128 outlined by a white dash line. The northern extension is based on limited data from drill holes (grey circle with triangle) and structures  
 129 within the gravity anomaly and total magnetic intensity images (data from Geoscience Australia) and thus remains speculative. Province  
 130 data acquired from the South Australian Resources Information Gateway (SARIG) and Geoscience Australia (Raymond 2018).

131 Historically, “Adelaidean” was used as a chronostratigraphic term of the era rank that was divided into the  
 132 Willouran, Torrensian, Sturtian and Marinoan periods (Drexel et al. 1993; Mawson & Sprigg 1950; Preiss  
 133 1987). This was prior to consensus definition of the Neoproterozoic era with Tonian, Cryogenian and  
 134 Ediacaran periods (Gradstein et al. 2005). Prior to 1995, much of the literature on the Adelaide Superbasin  
 135 uses these terms, which are not are not well defined with respect to time and had boundaries defined by  
 136 lithostratigraphic groups, some of which are now superseded, conflating chronostratigraphy and  
 137 lithostratigraphy. Although these should not be used as chronostratigraphic divisions today, historical  
 138 periods of the Adelaidean link with lithostratigraphic definitions (and broad time ranges) as follows:



- 139       • The Willouran period was defined as being represented by the Callanna Group; ca. 850–790 Ma.
- 140       • The Torrensian period began at the base of the Burra Group and continued through to the top of the
- 141       Bungarider Subgroup of the Burra Group; ca. 790–730 Ma.
- 142       • The Sturtian period stretched from the base of the Belair Subgroup of the Burra Group to the top of
- 143       Nepouie Subgroup of the Umberatana Group; ca. 730–640 Ma.
- 144       • The Marinoan period started at the base of the Upalinna Subgroup of the Umberatana Group,
- 145       continued through the remainder of the Umberatana Group to the top of the Wilpena Group; ca.
- 146       640–541 Ma.

147 These disused chronostratigraphic divisions are shown alongside the modern international

148 chronostratigraphic timescales in the updated stratigraphic correlation chart that can be found in *Data*

149 *Availability*. Sturtian and Marinoan are now restricted specifically to the names of the two “Snowball Earth”

150 glaciation events (Hoffman et al. 2017) and Adelaidean refers to the stratigraphy of the Adelaide Superbasin.

### 151 2.2.2. *Geology and Significance*

152 The development of the Adelaide Superbasin occurred as Laurentia (and possibly an intervening continent)

153 began to rift from Australia-East Antarctica within Rodinia. Sedimentation is suggested to have begun just

154 prior to ca. 830 Ma from gradual subsidence of a peneplained stable craton that developed into a rift basin

155 (Counts 2017; Powell 1998; Powell et al. 1994; Preiss 1987; 1988; 2000). After ca. 725 Ma—the latest time

156 for the break-up of Australia-East Antarctica and Laurentia, assuming Neoproterozoic plate velocities similar

157 to the Phanerozoic (Merdith et al. 2017b)—deposition within the Adelaide Superbasin continued in a mainly

158 passive margin setting along the western margin of the Palaeo-Pacific (Cawood 2005; Powell et al. 1994),

159 with renewed Ediacaran rifting and magmatism outboard of the major outcrop belts of the presently exposed

160 basin (Meffre et al. 2004). Deposition in the Adelaide Superbasin continued through to the middle Cambrian

161 (Powell 1998; Powell et al. 1994; Preiss 1987; 1988; 2000) and was terminated by the onset of the

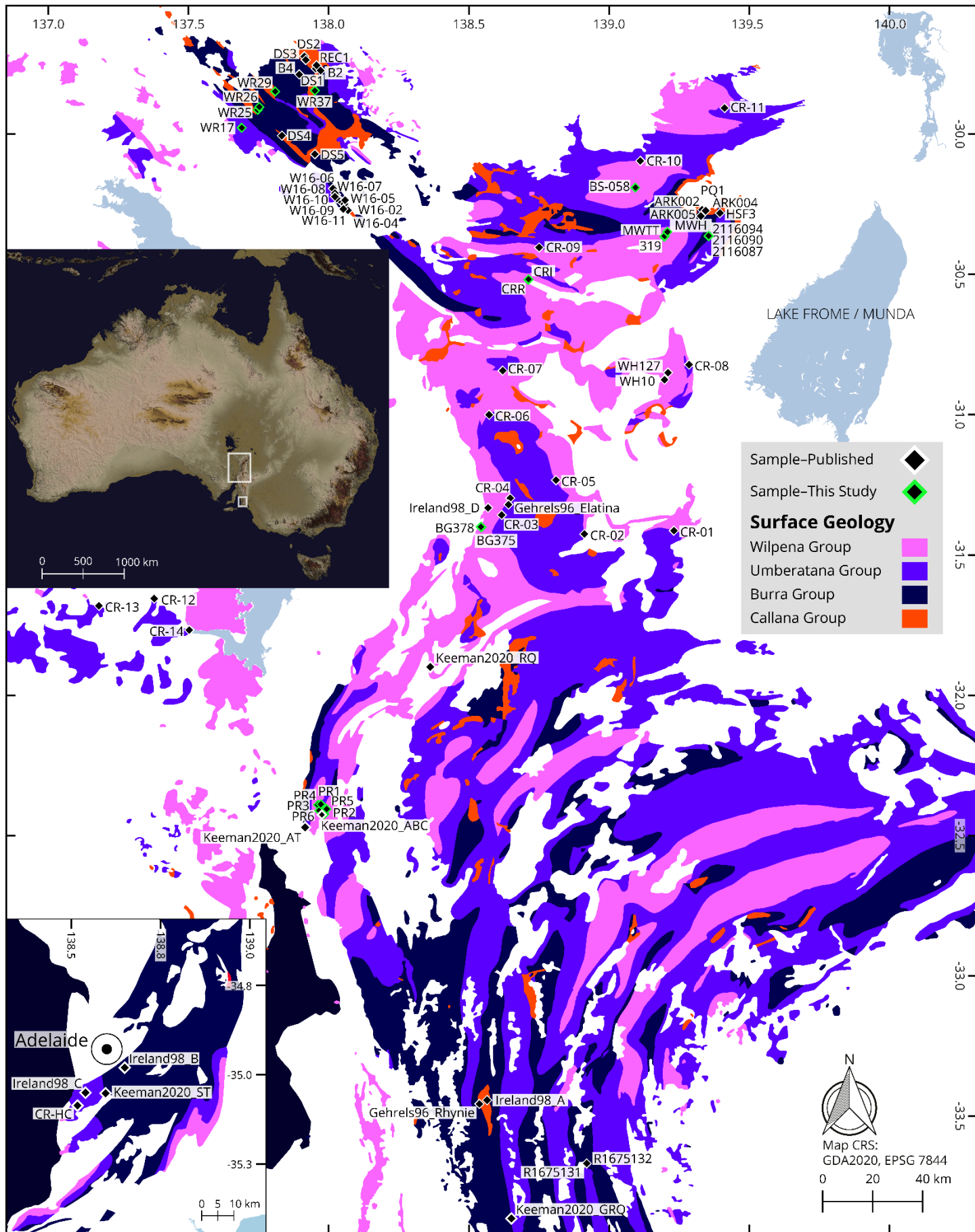
162 Delamerian Orogeny (Foden et al. 2006; Foden et al. 2020 ; Preiss 2000).

163 Deposition within the Adelaide Superbasin spans over 300 million years of Earth's history and stretches from



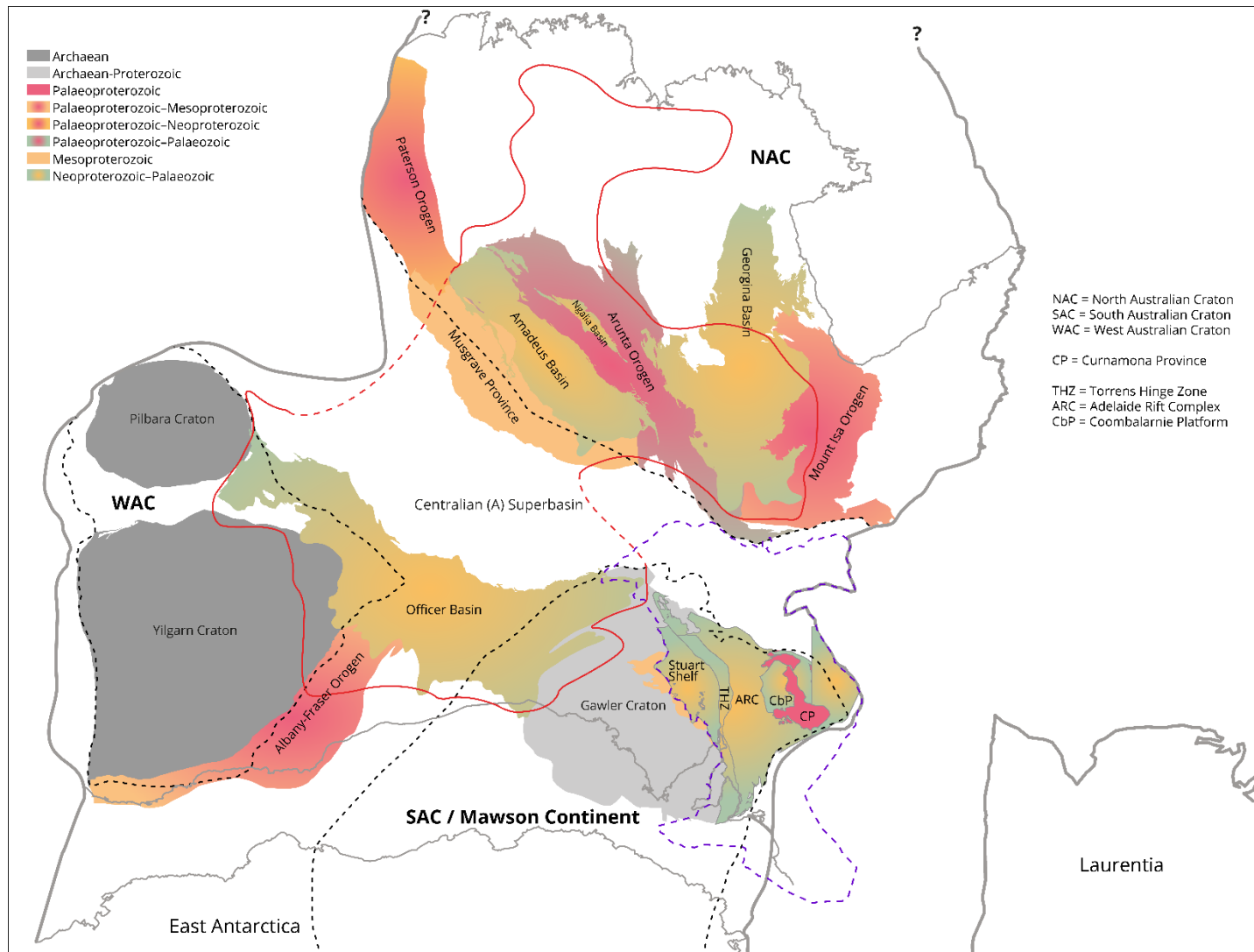
164 the northernmost regions of South Australia, narrowing in the South Mount Lofty Ranges at the Fleurieu  
165 Peninsula and extending into Kangaroo Island [Figure 1]. Although the original basin spans over 1,100  
166 kilometres in length from central Australia to the eastern tip of Kangaroo Island [Figure 1, Figure 1], the  
167 majority of the basin is buried beneath younger sedimentary basins; with approximately 600 km north–south  
168 cropping out day [Figure 4]. The northernmost extension of the Adelaide Superbasin is not well understood,  
169 but it has been suggested that the Muloorina Ridge [Figure 3]—a poorly understood gravity high previously  
170 interpreted as an ancient triple junction (von der Borch 1980)—may have been the northern limit of the basin  
171 until the late Ediacaran (Preiss 1987; 1990; Thomson 1970), although this remains speculative (Counts &  
172 Amos 2016). Walkandi-1 (Richards 1982) and Miandana-1 (Martin 1986) are two drill holes north of the  
173 Muloorina Ridge that have intersected stratigraphy described as Adelaidean, yet further correlation is  
174 speculative.





176 **Figure 4** – Sample locations and surface geology map of the Neoproterozoic Adelaide Rift Complex. Surface geology is shown by group.  
177 Top inset shows location relative to Australia (a false colour hill shade based on publicly available 7.5s SRTM DEM data from NASA).  
178 Bottom inset shows samples near Adelaide. A full list of sample locations can be found in the supplementary dataset (Lloyd et al. 2020)  
179 (link is provided in Data Availability). Surface geology data from SARIG.

180 To the west of the Adelaide Superbasin, the Gawler Craton [Figure 5] is comprised of Archaean and  
181 predominately Palaeoproterozoic to earliest Mesoproterozoic age rocks (Daly et al. 1998; Hand et al. 2007).  
182 Within the Gawler Craton, the major tectonic and magmatic events are: the Sleafordian Orogeny (2600–2400  
183 Ma), emplacement of the Donnington Granitoid Suite (1850–1840 Ma), the Lincoln Complex (Kimban  
184 Orogeny; 1790–1710 Ma), the Gawler Range Volcanics and associated intrusive Hiltaba suite at ca. 1590 Ma  
185 and a final emplacement event ca. 1450 Ma (Morrissey et al. 2019). It has been interpreted that the  
186 intrusion of the basaltic Gairdner Dyke Swarm at ca. 827 Ma (Wingate et al. 1998), was the result of a mantle  
187 plume associated with the initiation of rifting and formation of the Adelaide Superbasin. The Curnamona  
188 Province [Figure 5] lies to the east of the central Adelaide Superbasin and is late Palaeoproterozoic to early  
189 Mesoproterozoic in age, generally correlating with the younger components of the Gawler Craton (Coats &  
190 Blissett 1971; Compston et al. 1966; Elburg et al. 2001; Preiss 2000; Teale 1993; Willis et al. 1983). Preiss  
191 (2000) interpreted the existence of a late Palaeoproterozoic precursor basin occupying a similar extent to  
192 that of the Neoproterozoic Adelaide Rift Complex, with sedimentation and volcanism between ca. 1750–  
193 1650 Ma, and deformation at ca. 1600 Ma.



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195 **Figure 5** – Reconstruction of Neoproterozoic Australia, ca. 700 Ma, showing known extent of the Neoproterozoic component of the Adelaide Superbasin (Stuart Shelf, Adelaide Rift Complex,  
196 Coombararnie Platform, Torrens Hinge Zone), the proposed extent of the entire Adelaide Superbasin (purple dashed line, present day position), select Australian potential source terranes and  
197 coeval sedimentary basins. Black dashed lines represent boundaries of the North Australian Craton, South Australian Craton and West Australian Craton. The Centralian A Superbasin (Munson et  
198 al. 2013) is represented by a solid red line for modern day known extent and a dashed red line for inferred boundaries during the Neoproterozoic. Thick grey lines represent inferred  
199 Neoproterozoic continental outline and thinner grey lines represent modern day coastlines. Rotation of the NAC based on the model of Li and Evans (2010). Province data from Geoscience  
200 Australia (Raymond 2018) and SARIG. Original outline of Australia and Antarctica is from [www.naturalearthdata.com](http://www.naturalearthdata.com)



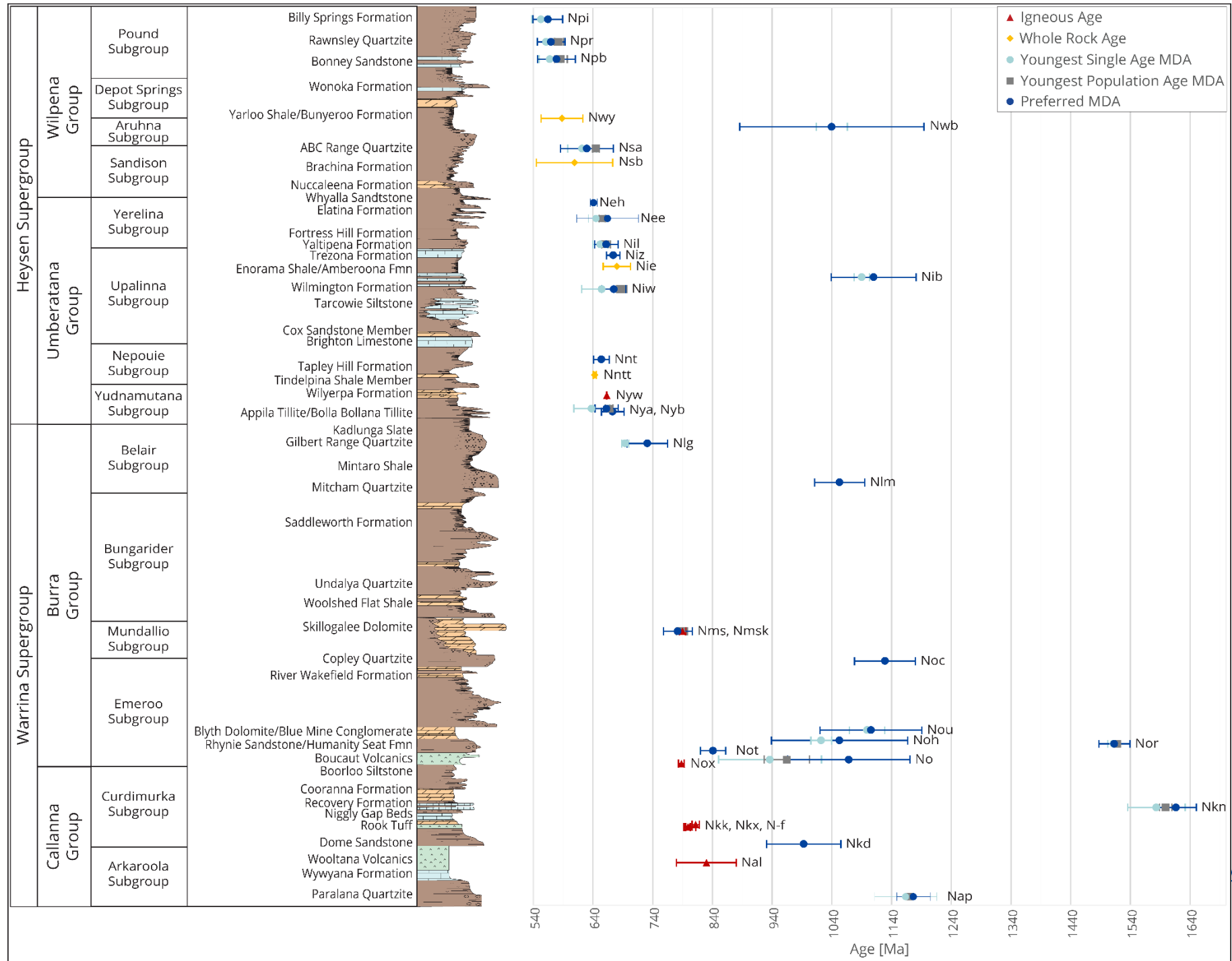
201 Within the Adelaide Superbasin there are at least five major rift cycles, each marked by associated  
202 faulting, minor volcanism, and distinct depositional sequences (Preiss 2000; Walter et al. 2000). It  
203 has been suggested that rifting within the Adelaide Superbasin initiated at ca. 827–802 Ma (Fanning  
204 et al. 1986; Jenkins et al. 2002; Wingate et al. 1998). The sedimentary sequences of the Adelaide  
205 Superbasin have been separated into three supergroups (Preiss 1982). The Warrina Supergroup that  
206 encompasses the Tonian early rift sequences, the Heysen Supergroup comprising the Cryogenian  
207 and Ediacaran glacial, interglacial and post-glacial sedimentary rocks, and the Moralana Supergroup  
208 that encompasses all the Cambrian sedimentary rocks (Preiss 1982; 2000). It is not well established  
209 when rifting terminated; however, evidence of large-scale normal faulting is not seen after the early  
210 Cryogenian (Preiss 2000). Deposition ceased and the sedimentary rocks were deformed and folded  
211 during the Cambro-Ordovician Delamerian Orogeny ca. 514–490 Ma (Drexel & Preiss 1995; Foden et  
212 al. 2006; Foden et al. 2020; Preiss 2000).

213 The Warrina Supergroup includes the Callanna and Burra Groups and is largely restricted to  
214 depositional fault-bound troughs (Powell et al. 1994). These groups are dominated by clastic and  
215 carbonate rocks, with evaporitic rocks and mafic volcanic rocks forming important constituents of  
216 the Callanna Group (Powell et al. 1994). The Heysen Supergroup, comprised of the Umberatana and  
217 Wilpena Groups, is considered to represent a period of thermal sag following deposition of the  
218 Warrina Supergroup that was largely controlled by tectonic subsidence (Preiss 1987). The  
219 Umberatana Group is made up of a thick interglacial succession (up to ~4.5 km thick) in the centre of  
220 the basin marked by the Sturtian glacial deposits (e.g. the Appila Tillite) defining the base, and the  
221 Marinoan glacial sequences (e.g., the Elatina Formation) characterising the top (Powell et al. 1994;  
222 Preiss 2000). The Wilpena Group records the Ediacaran post-glacial sequence, which shoals  
223 upwards into predominately sandstones (Powell et al. 1994; Preiss 2000). The two Neoproterozoic  
224 supergroups are followed by transgressive early Cambrian shallow-marine sandstones and deeper  
225 water carbonates and shales of the Moralana Supergroup, which includes all the Cambrian  
226 sedimentary rocks of the Adelaide Superbasin (Powell et al. 1994; Preiss 2000). Though not the

227 focus of this study, the Moralana Supergroup includes, the Normanville Group made of limestone;  
228 sandstone; shale and volcanics, the Kanmantoo Group including marine metasandstone, phyllite,  
229 schist, gneiss, minor calcsilicate and marble, and the Lake Frome Group, composed of sandstone,  
230 siltstone, shale, limestone and conglomerate (Zang et al. 2004). A tuff within the Normanville Group  
231 dates its deposition to  $514.98 \pm 0.63$  Ma (U–Pb TIMS; Betts et al. 2018), very close to the  $514 \pm 5$   
232 Ma crystallisation age of the Rathjen Gneiss (Foden et al. 1999), which is the oldest intrusion so-far  
233 dated into the overlying Kanmantoo Group (Foden et al. 2006).

234 The lack of reliable age constraints within the Adelaide Superbasin is in part due to the scarcity of  
235 syn-depositional (felsic) magmatism throughout the rock sequences. In addition, few detrital zircon  
236 studies have been undertaken. As a result, the depositional history, evolution of the basin  
237 sedimentary pathways and the wider tectonic geography of the area remain enigmatic. Preiss (2000)  
238 and Mahan et al. (2010) have previously summarised the available geochronology of the Adelaidean  
239 sedimentary rocks that were available at the time. Succeeding this, several studies have analysed  
240 detrital zircon from various formations from throughout the Neoproterozoic of the Adelaide  
241 Superbasin. Rose et al. (2013), published an extensive dataset of detrital zircon U–Pb ages from the  
242 Elatina Formation and equivalents. Cox et al. (2018), published a new U–Pb tuff age of  $663.03 \pm$   
243  $0.11$  Ma from the Wilyerpa Formation (in the Umberatana Group), as well as providing detrital zircon  
244 U–Pb age data from one sample of the Bolla Bollana Formation and one sample of the Tapley Hill  
245 Formation (mistakenly published as Bolla Bollana Formation) Most recently Keeman et al. (2020)  
246 published new data detrital zircon U–Pb geochronology and other isotopic data from a number of  
247 both Neoproterozoic and Cambrian formations of the Adelaide Superbasin. There have also been  
248 several research degree studies that have generated, but not formally published, detrital zircon U–Pb  
249 geochronology data (Drabsch 2016; Job 2011; Mackay 2011; Shahin 2016). All chronological ages  
250 from the Neoproterozoic of the Adelaide Superbasin discussed in this paper are summarised in  
251 Figure 6.





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253 **Figure 6 – [Right]** Composite, generalised and representative lithological log of the Neoproterozoic of the Adelaide Superbasin (adapted from Preiss (2000)). **[Left]** Within-basin chronological  
254 constraints relative to stratigraphic position. This lithological log does not represent the true thickness of lithologies, spatial variation of formations across the basin nor the detail of each  
255 formation. Chronology data and geochronology methods are detailed in Table 2 and linked by the associated map symbol (e.g. Npi). MDA is the maximum depositional age based on detrital zircon,  
256 details of the method for choosing MDAs are detailed in 3.3. The spatial relationships of these data are shown in Figure 7.



257 Using detrital muscovite  $^{40}\text{Ar}$ – $^{39}\text{Ar}$  data on formations with previously published detrital zircon U–Pb  
258 geochronology (Ireland et al. 1998), Haines et al. (2004) suggested that at the initiation of the infill of the  
259 basin, sediments were supplied from the younger parts of the Gawler Craton and Curnamona Province. The  
260 whole-rock Sm–Nd isotope data from the Neoproterozoic sedimentary rocks of the Adelaide Superbasin are  
261 also more radiogenic than most Gawler Craton basement, with the erosion of the Gairdner Dykes (and  
262 possible volcanic equivalents) being a possible explanation for this (Barovich & Foden 2000; Haines et al.  
263 2004). Through time, Adelaide Superbasin detritus shows progressive change to a more dominant ca. 1100  
264 Ma aged input, suggesting inundation from the Musgrave Orogen, to the north and west of the Gawler Craton  
265 [Figure 5] (Haines et al. 2004). Previous research has suggested that an abrupt change in detrital zircon ages  
266 occurs at the base of the Cambrian Kanmantoo Group, where Ediacaran/Cambrian (600–500 Ma) and  
267 Stenian 1200–1000 Ma dominate (Ireland et al. 1998). This may reflect a late influx of southerly-derived  
268 detritus as subduction of the Pacific Ocean began forming topography as the Ross Orogen developed (Foden  
269 et al. 2006).

### 270 **3. Methods**

271 Data were obtained from publications, theses, and analyses of new samples from relatively understudied  
272 formations within the Neoproterozoic of the Adelaide Superbasin—Figure 4 shows the locations of samples  
273 in used this study. All data was subject to the same statistical analysis as outlined in section 3.3. The link to  
274 the U–Pb detrital zircon dataset for the Adelaide Rift Complex is found in *Data Availability*.

#### 275 *3.1. Prior Data*

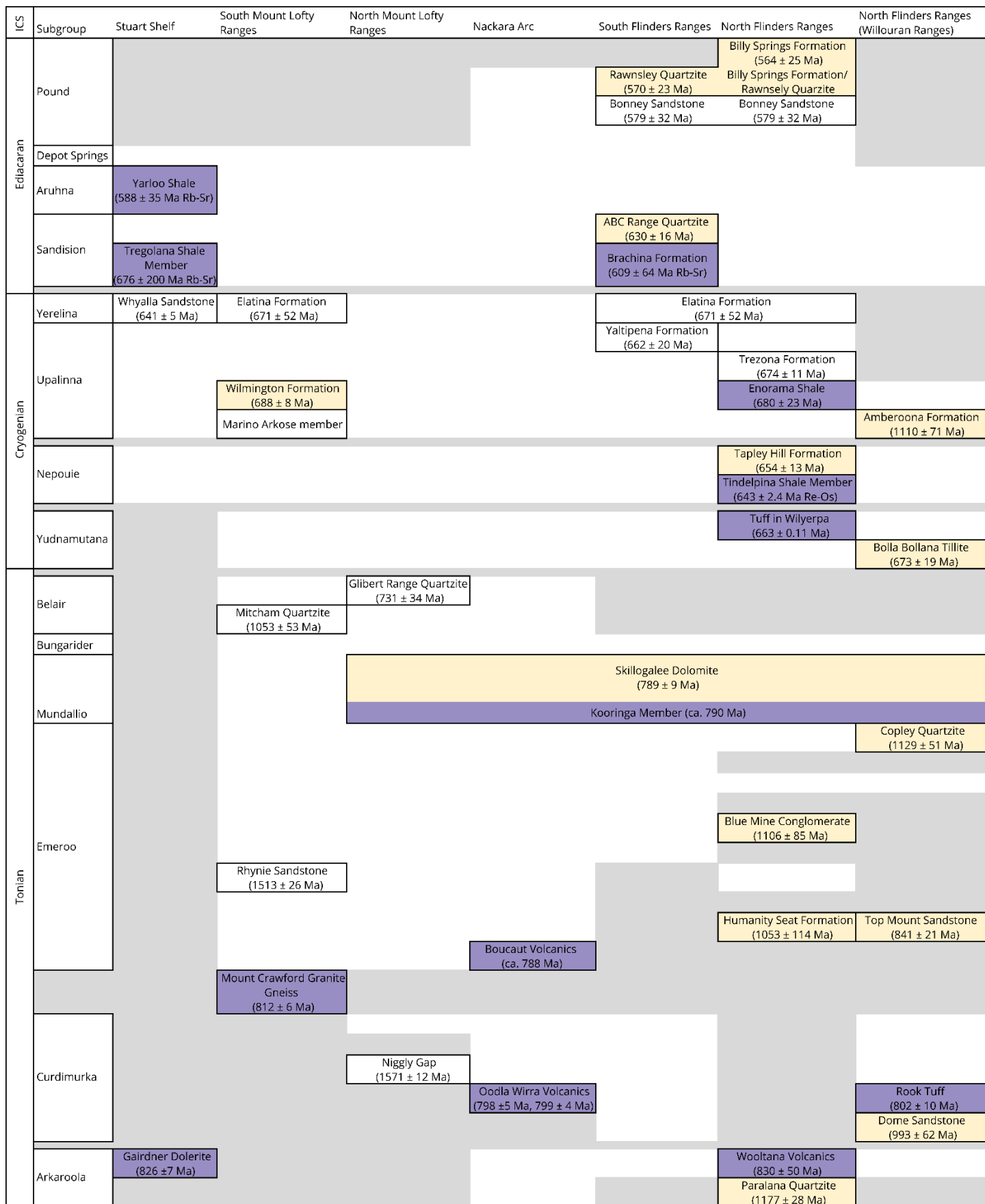
276 Detrital zircon data was collated from prior peer-reviewed publications and theses, constituting a total of 55  
277 samples from 23 formations, and two samples from an undifferentiated Emeroo subgroup lithology [Figure  
278 4]. The formations these data are from are—in reverse stratigraphic order (oldest first)—the Paralana  
279 Quartzite, the Dome Sandstone, the Recovery Formation, the Niggly Gap Beds, the Humanity Seat Formation,  
280 the Emeroo Subgroup (undifferentiated), the Rhynie Sandstone, the Blue Mine Conglomerate, the Copley  
281 Quartzite, the Skillogalee Dolomite, the Mitcham Quartzite, the Gilbert Range Quartzite, the Bolla Bollana



282 Tillite, the Appila Tillite, the Tapley Hill Formation, the Wilmington Formation (Marino Arkose Member), the  
283 Yaltipena Formation, the Trezona Formation, the Elatina Formation, the Whyalla Sandstone, the ABC Range  
284 Quartzite, the Bunyeroo Formation, the Bonney Sandstone, and the Rawnsley Quartzite.

285 Of these, 34 samples from 15 formations are published in peer reviewed journals (Compston et al. 1987; Cox  
286 et al. 2018; Gehrels et al. 1996; Ireland et al. 1998; Keeman et al. 2020; Preiss et al. 2009; Rose et al.  
287 2013). The remainder of these data are from research theses (Drabsch 2016; Job 2011; Shahin 2016;  
288 Mackay 2011). Figure 7 shows the spatial, stratigraphic and time relationships of the formations these data  
289 are from, highlighting the saturations and gaps in our current knowledge base, the importance of formally  
290 publishing the theses data, and directing the ongoing and future research to fill the gaps in our current  
291 knowledge base.





293 **Figure 7** – Current chronological constraints within the Neoproterozoic of the Adelaide Superbasin with relation to spatial and  
294 stratigraphic position. Purple shading indicates non-detrital constraints (Compston et al. 1987; Cox et al. 2018; Fabris et al. 2005;  
295 Fanning et al. 1986; Kendall et al. 2006; Mahan et al. 2010; Preiss et al. 2009; Preiss et al. 2008; Webb 1980; Wingate et al. 1998),  
296 yellow shading represents new and these data, and grey shaded areas represent unconformities as per previous literature. White  
297 bounded boxes are prior peer-reviewed detrital zircon data (Gehrels et al. 1996; Gostin et al. 1986; Ireland et al. 1998; Keeman et al.  
298 2020; Rose et al. 2013). This is not a complete stratigraphic correlation of the Adelaide Superbasin, and gaps in chronological data are  
299 represented by the white shaded, non-bordered areas. Geographic regions are defined in Figure 1

### 300 3.2. *New Data*

301 Twenty-two new samples from nine formations were analysed for U–Pb detrital zircon data. The formations  
302 these data are from are—in reverse stratigraphic order—the Top Mount Sandstone, the Skillogalee Dolomite,  
303 the Amberoona Formation, the Elatina Formation, the Wilmington Formation, the ABC Range Quartzite, the  
304 Bonney Sandstone, the Rawnsley Quartzite, and the Billy Springs Formation.

#### 305 3.2.1. *U–Pb Geochronology*

306 All new zircon samples were imaged via cathodoluminescence on an XL40 scanning electron microscope and  
307 analysed using Laser Ablation Inductively Coupled Plasma Mass Spectrometry (LA-ICP-MS). Two different  
308 instruments were used to obtain data from these new samples. Analysis was either conducted on a  
309 Resonetics M50-193 laser ablation system coupled with an Agilent 7700s ICP-MS or a New Wave UP-213  
310 laser ablation system coupled with an Agilent 7500cs ICP-MS, both instruments are housed at Adelaide  
311 Microscopy, University of Adelaide, Australia. Analytical methodology followed standard methods of Payne et  
312 al. (2006). A variety of primary and secondary standards were analysed every 10–20 unknowns. These were  
313 GEMOC GJ-1 (TIMS normalising ages  $^{207}\text{Pb}/^{235}\text{U}$   $602.0 \pm 1.0$  Ma;  $^{206}\text{Pb}/^{238}\text{U}$   $600.7 \pm 1.1$  Ma;  $^{207}\text{Pb}/^{206}\text{Pb}$   $607.7$   
314  $\pm 4.3$  Ma; Jackson et al. 2004), Plešovice (ID-TIMS  $^{206}\text{Pb}/^{238}\text{U}$  Age,  $337.13 \pm 0.37$  Ma; Sláma et al. 2008),  
315 91500 (TIMS  $^{207}\text{Pb}/^{206}\text{Pb}$   $1065.4 \pm 0.3$  Ma; Wiedenbeck et al. 1995) and an in-house Sri Lankan zircon  
316 standard (BJWP-1; ca. 727 Ma). Data were processed either using GLITTER (Jackson et al. 2004) or Iolite  
317 (Paton et al. 2011) depending on the year collected. Standards data are presented in Table 1.



**Table 1** - Standards Data

Samples	Equipment	Processing Software	Standard		$^{207}\text{Pb}/^{235}\text{U}$	$^{206}\text{Pb}/^{238}\text{U}$	$^{207}\text{Pb}/^{206}\text{Pb}$
PR1, PR2, PR3, PR4, PR5, PR6	New Wave UP-213 laser with Agilent 7500cs ICP-MS	GLITTER	GEMOC GJ-1	Primary	601.5 ± 0.86 Ma; MSWD = 1.50	600.37 ± 0.82 Ma; MSWD = 0.92	605.5 ± 4 Ma; MSWD = 0.86
			Plešovice	Secondary	329.88 ± 0.84 Ma; MSWD = 2.60	331.62 ± 0.76 Ma; MSWD = 2.80	317.40 ± 6.10 Ma; MSWD = 0.98
2116087, 2116090, 2116094	New Wave UP-213 laser with Agilent 7500cs ICP-MS	GLITTER	GEMOC GJ-1	Primary	600.24 ± 0.77 Ma; MSWD = 0.96	600 ± 0.76 Ma; MSWD = 0.70	602.29 ± 3.22 Ma; MSWD = 0.65
			Plešovice	Secondary	328.76 ± 0.83 Ma; MSWD = 1.65	332.19 ± 0.72 Ma; MSWD = 3.00	316 ± 5.71 Ma; MSWD = 0.96
058 (03/07/2014)	New Wave UP-213 laser with Agilent 7500cs ICP-MS	GLITTER	GEMOC GJ-1	Primary	602.27 ± 1.06 Ma; MSWD = 1.31	600.89 ± 0.91 Ma; MSWD = 0.96	608.79 ± 5.08 Ma; MSWD = 0.82
			Plešovice	Secondary	340.32 ± 1.23 Ma; MSWD = 28.8	336.88 ± 0.83 Ma; MSWD = 112	334.62 ± 9.86 Ma; MSWD = 0.54
058 (15/09/2014)	New Wave UP-213 laser with Agilent 7500cs ICP-MS	GLITTER	GEMOC GJ-1	Primary	602.34 ± 1.84 Ma; MSWD = 0.61	600.53 ± 1 Ma; MSWD = 0.82	611.50 ± 9 Ma; MSWD = 0.64
			BJWP-1	Secondary	657.54 ± 3.41 Ma; MSWD = 7.51	646.42 ± 1.68 Ma; MSWD = 19.3	723 ± 15.4 Ma; MSWD = 1.76
058 (16/09/2014)	New Wave UP-213 laser with Agilent 7500cs ICP-MS	GLITTER	GEMOC GJ-1	Primary	602.45 ± 1.90 Ma; MSWD = 0.26	599.87 ± 1.05 Ma; MSWD = 0.66	612.65 ± 9.39 Ma; MSWD = 0.33
			BJWP-1	Secondary	726.88 ± 5.40 Ma; MSWD = 0.34	702.79 ± 2.68 Ma; MSWD = 0.97	811.4 ± 22.7 Ma; MSWD = 0.49
319	New Wave UP-213 laser with Agilent 7500cs ICP-MS	GLITTER	GEMOC GJ-1	Primary	602.12 ± 1.09 Ma; MSWD = 0.36	600.37 ± 0.64 Ma; MSWD = 0.60	608.90 ± 5.39 Ma; MSWD = 0.29
			BJWP-1	Secondary	707.58 ± 2.96 Ma; MSWD = 0.89	688.89 ± 1.57 Ma; MSWD = 0.70	771.8 ± 12.8 Ma; MSWD = 0.84
BG375	New Wave UP-213 laser with Agilent 7500cs ICP-MS	GLITTER	GEMOC GJ-1	Primary	602.26 ± 1.77 Ma; MSWD = 0.51	600.16 ± 0.97 Ma; MSWD = 0.48	608.17 ± 8.69 Ma; MSWD = 0.44
			BJWP-1	Secondary	719.16 ± 5.08 Ma; MSWD = 0.62	715.60 ± 2.56 Ma; MSWD = 0.45	740.1 ± 22.3 Ma; MSWD = 0.48
BG378	New Wave UP-213 laser with Agilent 7500cs ICP-MS	GLITTER	GEMOC GJ-1	Primary	601.31 ± 1.46 Ma; MSWD = 0.67	599.65 ± 0.82 Ma; MSWD = 1.52	611.40 ± 7.16 Ma; MSWD = 0.40
			BJWP-1	Secondary	724.23 ± 3.51 Ma; MSWD = 0.75	706.98 ± 1.85 Ma; MSWD = 0.63	774.8 ± 14.5 Ma; MSWD = 0.57



**Table 1** - Standards Data

Samples	Equipment	Processing Software	Standard		$^{207}\text{Pb}/^{235}\text{U}$	$^{206}\text{Pb}/^{238}\text{U}$	$^{207}\text{Pb}/^{206}\text{Pb}$
CRI	New Wave UP-213 laser with Agilent 7500cs ICP-MS	GLITTER	GEMOC GJ-1	Primary	601.74 ± 1.67 Ma; MSWD = 0.56	601.08 ± 0.98 Ma; MSWD = 0.83	609.63 ± 8.17 Ma; MSWD = 0.33
			BJWP-1	Secondary	728.02 ± 4.33 Ma; MSWD = 0.56	719.27 ± 2.33 Ma; MSWD = 0.64	752.8 ± 18.2 Ma; MSWD = 0.68
CRR	New Wave UP-213 laser with Agilent 7500cs ICP-MS	GLITTER	GEMOC GJ-1	Primary	602.41 ± 1.44 Ma; MSWD = 0.66	601.24 ± 0.82 Ma; MSWD = 0.84	609.19 ± 7.06 Ma; MSWD = 0.38
			BJWP-1	Secondary	712.61 ± 3.50 Ma; MSWD = 0.86	701.11 ± 1.75 Ma; MSWD = 1.13	749.2 ± 14.9 Ma; MSWD = 0.64
MWH	New Wave UP-213 laser with Agilent 7500cs ICP-MS	GLITTER	GEMOC GJ-1	Primary	602.25 ± 1.53 Ma; MSWD = 0.56	600.01 ± 0.83 Ma; MSWD = 1.35	610.33 ± 7.53 Ma; MSWD = 0.41
			BJWP-1	Secondary	640.66 ± 2.79 Ma; MSWD = 7.53	640.67 ± 1.45 Ma; MSWD = 22.2	689.6 ± 13.2 Ma; MSWD = 1.39
MWTT	New Wave UP-213 laser with Agilent 7500cs ICP-MS	GLITTER	GEMOC GJ-1	Primary	602.10 ± 0.87 Ma; MSWD = 0.42	600.40 ± 0.67 Ma; MSWD = 0.33	608.34 ± 4.11 Ma; MSWD = 0.39
			BJWP-1	Secondary	684.29 ± 2.0 Ma; MSWD = 0.64	665.95 ± 1.37 Ma; MSWD = 0.77	741.41 ± 8.47 Ma; MSWD = 0.49
WR17, WR25, WR26, WR29, WR37	Resonetics M50-193 laser with Agilent 7700s ICP-MS	IOLITE	GEMOC GJ-1	Secondary	605.27 ± 1.15 Ma; MSWD = 0.30	601.81 ± 0.60 Ma; MSWD = 0.45	618.22 ± 5.68 Ma; MSWD = 0.31
			Plešovice	Secondary	338.40 ± 1.41 Ma; MSWD = 0.51	338.51 ± 0.34 Ma; MSWD = 0.71	343.41 ± 5.77 Ma; MSWD = 0.34
			91500	Primary	1059.38 ± 3.1 Ma; MSWD = 0.35	1053.42 ± 2.51 Ma; MSWD = 0.36	1080.2 ± 12.6 Ma; MSWD = 0.28





### 319 3.3. Statistics

320 The entire dataset was analysed with the following statistical methodology to ensure consistency,  
321 reproducibility, and comparability. To determine a *preferred age* (aka best age) for an individual analysis we  
322 utilise the precision method (model-1) of Puetz (2018), whereby the best age is the most precise of the  
323  $^{206}\text{Pb}/^{238}\text{U}$ ,  $^{207}\text{Pb}/^{235}\text{U}$  and  $^{206}\text{Pb}/^{207}\text{Pb}$  ages. The *preferred age* must also pass a test for 'reasonable ages'  
324 where  $0 \text{ Ma} < X \leq 4300 \text{ Ma}$ . *Preferred ages* are then subsequently filtered into *filtered ages* by a formula that  
325 checks if the concordance for that grain is between 90 and 110, and that the relative uncertainty of the  
326 *preferred age* is less than 10%. Where the  $^{207}\text{Pb}/^{235}\text{U}$  age is available concordance is calculated by using  
327  $(\frac{[^{206}\text{Pb}/^{238}\text{U}]/[^{207}\text{Pb}/^{235}\text{U}]}{[^{207}\text{Pb}/^{235}\text{U}]/[^{207}\text{Pb}/^{206}\text{Pb}]}*100)$  for *preferred ages* of less than 1000 Ma and  $(\frac{[^{206}\text{Pb}/^{238}\text{U}]/[^{207}\text{Pb}/^{235}\text{U}]}{[^{207}\text{Pb}/^{235}\text{U}]/[^{207}\text{Pb}/^{206}\text{Pb}]}*100)$  for  
328 *preferred ages* of 1000 Ma or older. If the  $^{207}\text{Pb}/^{235}\text{U}$  age is not available concordance is calculated by using  
329  $(\frac{[^{206}\text{Pb}/^{238}\text{U}]/[^{207}\text{Pb}/^{206}\text{Pb}]}{[^{207}\text{Pb}/^{235}\text{U}]/[^{207}\text{Pb}/^{206}\text{Pb}]}*100)$ . Concordance values are rounded to the nearest whole integer. This method  
330 for calculating concordance is identical, with respect to the decay systems, to that of Puetz et al. (2018).  
331 These parameters were defined in order to retain a large dataset, prevent human bias, and discard  
332 datapoints with significantly large uncertainties on near concordant data whilst also taking into account the  
333 relative changes in precision and accuracy of the decay systems through time (Puetz et al. 2018; Spencer et  
334 al. 2016). The concordance cut off percentage was explored at lesser values using a cumulative distribution  
335 function to visualise the distribution of the data. No real benefit was gained using a concordance cut off  
336 between 5% and 9% and setting it at 5% would have meant discarding approximately 1000 data points,  
337 equating to approximately 19% of the filtered data set. All preferred ages, and subsequently filtered ages,  
338 used in construction of statistical plots were chosen from original data in an unbiased manner using a  
339 formula in Microsoft® Excel™ based on the previously described parameters. Formulas and detailed  
340 explanations of their operation are found in the workbook linked in *Data Availability*.

341 Grouping data by formation, these data were statistically explored using kernel density estimates (KDE) and  
342 multidimensional scaling (MDS). KDE and MDS plots were generated using IsoplotR (Vermeesch 2018b) with  
343 KDEs using a common bandwidth to aid visual comparison. The common bandwidth is the median bandwidth  
344 of the automatically generated variable bandwidths of all samples (Vermeesch 2018b). MDS plots generated

345 using IsoplotR use the Kolmogorov-Smirnov (KS) statistic (Vermeesch 2013; 2018b). Synthetic peaks for the  
346 MDS plots were generated using the random number generator function of Excel™ to create 1000 points with  
347 a standard deviation based on the estimated two sigma uncertainty equation from Puetz et al. (2018). These  
348 synthetic peaks are an estimate of most prominent peaks (local maxima) within a KDE that combines all  
349 filtered data from the ARC and are meant to act as anchors in the MDS to help guide the viewer to visualise  
350 the components that contribute to the similarities of points within the MDS. The MDS plot allows us to  
351 visualise relationships more easily between the formations, although these must be used with larger  
352 amounts of data for more robust statistics, as such any formation with less than 40 filtered ages was  
353 omitted. Care must be taken to only use geographically probable sources for comparative data as sources  
354 that are not geographically probable may have similar age spectra as the terrane under investigation. Whilst  
355 Nordsvan et al. (2020) highlight limitations of this method of MDS analysis, we use it only to look at relative  
356 differences and there is no real need to explicitly account for analytical uncertainty (Vermeesch 2012;  
357 2018a).

358 The multiple sample, 'view from above' probability density plot (PDP) was generated using FitPDF (Eglington  
359 2018). Although both KDE and PDP have advantages and disadvantages with relation to each other, the  
360 authors of this paper prefer the use of KDE for statistical analysis for reasons highlighted by Vermeesch  
361 (2012). FitPDF limits the user to PDPs, however, the program provides a particularly useful way to visualise  
362 the relative changes in peak density for many samples over time. With our large dataset and use of a  
363 precision method to determine *preferred* ages for each analysis, the PDP and KDE plots should effectively  
364 look the same.

365 In this paper, we generally quote youngest single grain (YSG) ages as maximum depositional ages (MDA)  
366 rather than quoting the means of age clusters. One reasoning is that there is no *a priori* reason that any two  
367 detrital zircon grains should have the same age within any particular sample (Dickinson & Gehrels 2009;  
368 Spencer et al. 2016; Yang et al. 2018). The data for use as YSG for MDA is determined using the same  
369 methodology as *filtered* ages, described earlier in this section, but with a much stricter concordance level of  
370 within 2% of concordance (calculated as described earlier in this section). From this we generally use the

371 older of the  $^{207}\text{Pb}/^{206}\text{Pb}$ ,  $^{207}\text{Pb}/^{235}\text{U}$  and  $^{206}\text{Pb}/^{238}\text{U}$  ages as a conservative estimate for the maximum  
372 depositional age, this is termed the *preferred* MDA [Table 2]. For completeness, the weighted mean age of  
373 clusters (youngest population age, YPA) and MSWD is provided and is calculated using a formula that  
374 averages grains that overlap within uncertainty of the youngest grain plus its uncertainty—this only applies  
375 when  $n$  grains of the youngest overlapping population is greater than two. We utilise the equations of Wendt  
376 and Carl (1991) and Spencer et al. (2016) for the calculation of the weighted mean and reduced chi-squared  
377 statistic (MSWD). If there is genuine concern about the reliability of the YSG we use the YPA. The Wetherill  
378 concordia plots for our new data were generated using IsoplotR (Vermeesch 2018b) and can be found in  
379 Appendix One.

#### 380 **4. Results**

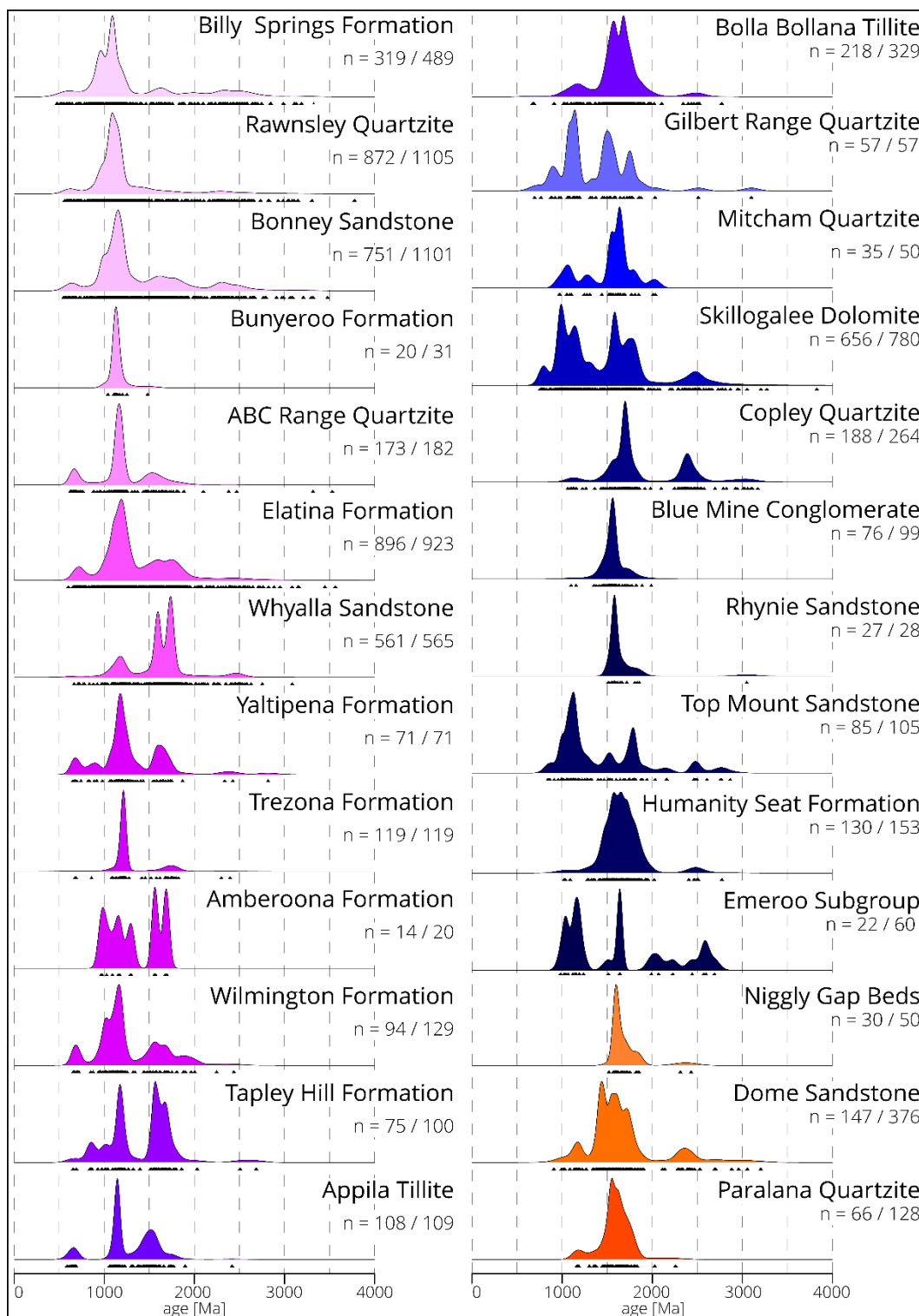
381 Analysis of the twenty-two new samples yielded 3,506 new U–Pb detrital zircon datum of which 2,596 are  
382 within filtering parameters. Concordia diagrams and individual kernel density estimates for these new  
383 samples can be found in Appendix One. The remainder of the data set is from the 57 samples from prior data  
384 that is outlined earlier. These remaining samples constitute 4,090 data; 3,192 of these are within filtering  
385 parameters. The original data from these sources was reanalysed with the same statistical methodology as  
386 the unpublished data set. The results in this paper may vary from the original publications due to variations  
387 in the statistical methods used by those authors compared with the methodology described in section 3.3.  
388 The entire dataset covers the above mentioned 27 formations with a total of 7,596 data; 5,788 of these are  
389 within filtering parameters described in section 3.3. Sample locations are shown on Figure 4 and coordinates  
390 can be found in the database linked in *Data Availability*. Kernel density estimates, grouped by formation are  
391 shown in Figure 8. In the following subsections [4.1, 4.2, 4.3, & 4.4] we describe the results of the entire  
392 compiled dataset, referring to *filtered* zircons, which simply means zircon that fit our filtering parameters for  
393 concordance, relative uncertainty and are a “reasonable age” (i.e. greater than 0 Ma and less or equal to  
394 4301 Ma). Maximum depositional ages are interpreted later in section 5.1.4.

395 The combined dataset is grouped by formation and plotted as kernel density estimates [Figure 8], and a  
396 “view from above” probability density plot [Figure 9] used to highlight changes in population probabilities



397 through time with similarities/dissimilarities visualised in multidimensional scaling plots [Figure 10]. Figure 5  
398 shows potential Australian source regions, coeval sedimentary basins and reconstruction of Neoproterozoic  
399 Australia ca. 700 Ma, a key time just after the start of the Sturtian Glaciation (Hoffman et al. 2017) and  
400 inferred separation of Laurentia and Australia-East Antarctica (Merdith et al. 2017a).





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**Figure 8** – Kernel density estimates (KDEs) for all data presented in this publication, grouped by formation. These KDEs contain filtered data (based on concordance and relative error) only with the Recovery Formation being omitted due to only having two analyses within the filtering parameters. The markers below each KDE represent the individual data points. For details on the filtering parameters see section 3.3. The KDEs are arranged in stratigraphic order with the Paralana Quartzite being the oldest and the Billy Springs Formation being the youngest. Plotted using IsoplotR (Vermeesch 2018b)



407 4.1. *Callanna Group*

408 4.1.1. *Paralana Quartzite*

409 Samples for the Paralana Quartzite come from Job (2011) (ARK002) and Mackay (2011) (PQ1) [Figure 4].  
410 The 66/128 filtered zircons range from  $2259 \pm 25$  Ma to  $1164 \pm 52$  Ma with a bimodal major population peak  
411 ca. 1600–1560 Ma tailing toward 1800 Ma, a minor peak at ca. 1170 Ma, scattered ages between 1500–  
412 1300 Ma, and two analyses over ca. 1830 Ma at  $2259 \pm 25$  Ma and  $2027 \pm 54$  Ma.

413 4.1.2. *Dome Sandstone*

414 The five samples (DS1-DS5) [Figure 4] for the Dome Sandstone come from Mackay (2011). The 147/376  
415 filtered zircons range between  $3204 \pm 33$  Ma and  $908 \pm 72$  Ma with major population peaks at ca. 1720 Ma,  
416 1600–1560 Ma, and 1440 Ma. There are two minor peaks at ca. 2370 Ma and ca. 1170 Ma, the latter tailing  
417 toward ca. 1000 Ma. There are scattered zircon ages between these populations and above ca. 2500 Ma with  
418 three zircons ca. 3000 Ma.

419 4.1.3. *Recovery Formation*

420 While Mackay (2011) report only 14 rejected analyses from the total 72 for sample REC1, our filtering  
421 parameters yield only two filtered analyses with ages of  $924 \pm 52$  Ma and  $770 \pm 22$  Ma.

422 4.1.4. *Niggly Gap Beds*

423 Data for the Niggly Gap Beds come from one sample published by Ireland et al. (1998) (Ireland98\_A) [Figure  
424 4]. The 30/50 filtered zircon analyses range in age between  $2431 \pm 22$  Ma and  $1520 \pm 24$  Ma, with one major  
425 population peak at ca. 1600 Ma tailing toward a minor peak at ca. 1800 Ma. There are two zircons above ca.  
426 1850 Ma at  $2431 \pm 22$  Ma and  $2312 \pm 26$  Ma.

427 4.2. *Burra Group*

428 4.2.1. *Emeroo Subgroup (undifferentiated)*

429 Sample B2 [Figure 4] of Mackay (2011) is described as coming from the base of the Emeroo Subgroup in the  
430 Willouran Ranges. The 22/60 filtered zircon ages range between  $2691 \pm 22$  Ma and  $982 \pm 8$  Ma with peaks  
431 ca. 2480 Ma, ca. 1570 Ma, ca. 1110 Ma, and ca. 1000 Ma.

432 4.2.2. *Humanity Seat Formation*

433 Samples from the Humanity Seat Formation come from Job (2011) (ARK004) and Mackay (2011) (HSF3)  
434 [Figure 4]. There are 130/153 filtered ages for the Humanity Seat Formation ranging between  $2775 \pm 25$  Ma  
435 and  $1022 \pm 17$  Ma. There is a major bimodal population between ca. 1580 Ma and ca. 1500 Ma with a slight  
436 tail toward ca. 1800 Ma. Minor populations are present ca. 2400 Ma and ca. 1050 Ma.

437 4.2.3. *Top Mount Sandstone*

438 Sample WR37 is a new sample published in this study and comes from the Top Mount Sandstone of the  
439 Willouran Ranges [Figure 1, Figure 4]. The 85/105 filtered zircon ages range between  $2867 \pm 27$  Ma and  $841$   
440  $\pm 21$  Ma, with major population peaks at ca. 1800 Ma and ca. 1080 Ma. Minor peaks are present at ca. 2480  
441 Ma, and ca. 1530 Ma with scattered zircon ages between these populations and above ca. 2500 Ma.

442 4.2.4. *Rhynie Sandstone*

443 The Rhynie Sandstone data come from a single sample published by Gehrels et al. (1996)  
444 (Gehrels96\_Rhynie) [Figure 4]. The 27/28 filtered ages range from  $3050 \pm 4$  Ma to  $1512 \pm 10$  Ma and form  
445 an almost exclusive peak ca. 1600 Ma tailing toward ca. 1800 Ma with just one zircon older than ca. 1850  
446 Ma.

447 4.2.5. *Blue Mine Conglomerate*

448 Sample ARK005 (Job 2011) [Figure 4] is the only sample from the Blue Mine Conglomerate. The 76/99  
449 filtered zircon ages range between  $1990 \pm 27$  Ma and  $1099 \pm 30$  Ma forming one major peak ca. 1580 Ma  
450 and a minor peak ca. 1730 Ma.

451 4.2.6. *Copley Quartzite*

452 Drabsch (2016) collected four samples of the Copley Quartzite, W16-02, W16-04, W16-05, and W16-11,  
453 from the Willouran Ranges [Figure 1, Figure 4]. The 188/264 filtered zircon ages range between  $3172 \pm 26$   
454 Ma and  $1062 \pm 22$  Ma forming major population peaks at ca. 2400 Ma and ca. 1700 Ma, with minor  
455 populations at ca. 3000 Ma, ca. 1580 Ma tailing toward 1500 Ma, and ca. 1100 Ma.



456 4.2.7. *Skillogalee Dolomite*

457 Data for four samples, W16-01 (Drabsch 2016), B4 (Mackay 2011), R1675131 and R1675132 (Preiss et al.  
458 2009) are available in existing literature [Figure 4]. In total we publish another six samples, from the  
459 Arkaroola area (2116087, 2116090, and 2116094) and Willouran Ranges (WR25, WR26, and WR29) [Figure  
460 4]. The 656/780 filtered zircon ages range between  $3825 \pm 20$  Ma and  $754 \pm 22$  Ma forming two major  
461 bimodal populations at ca. 1760 Ma/1580 Ma and ca. 1140 Ma/1000 Ma and minor population peaks at ca.  
462 795 Ma and ca. 2480 Ma. It is worthwhile noting the spatial variation of these samples as the oldest grains  
463 mostly come from the northern regions of the ARC and the majority of the zircons with ages <800 Ma come  
464 from the central part of the ARC. The oldest zircon in this study,  $3825 \pm 20$  Ma is found in sample W16-01.

465 4.2.8. *Mitcham Quartzite*

466 The Mitcham Quartzite data comes from one sample published by Ireland et al. (1998) (Ireland98\_B) [Figure  
467 4]. The 35/50 filtered zircon ages range between  $2035 \pm 38$  Ma and  $967 \pm 26$  Ma with a bimodal major  
468 population peak at ca. 1630 Ma/1560 Ma. Minor zircon populations are present at ca. 2000 Ma, ca. 1280 Ma,  
469 and ca. 1080 Ma.

470 4.2.9. *Gilbert Range Quartzite*

471 Data for the Gilbert Range Quartzite was recently published by Keeman et al. (2020) (Keemana2020\_GRQ)  
472 [Figure 4]. We obtain 57/57 filtered zircon ages of the same age range between ca. 3100 Ma and ca. 700 Ma  
473 as those authors. Major zircon age populations are present at ca. 1740 Ma, ca. 1500 Ma, ca. 1140 Ma, and  
474 ca. 1080 Ma. A minor population is present ca. 890 Ma.

475 4.3. *Umberatana Group*

476 4.3.1. *Bolla Bollana Tillite*

477 Four samples (W16-6, W16-7, W16-8, and W16-9) of Bolla Bollana Tillite were acquired from the Willouran  
478 Ranges and analysed by (Shahin 2016) [Figure 1, Figure 4]. The 218/329 filtered zircon ages range between  
479  $2771 \pm 63$  Ma and  $673 \pm 19$  Ma, with major population peaks at ca. 1680 Ma and ca. 1580 Ma. Minor  
480 populations are present ca. 2500 Ma and ca. 1180 Ma.



481 4.3.2. *Appila Tillite*

482 Data for the Appila Tillite, sampled in the South Flinders Ranges, were recently published by Keeman et al.  
483 (2020) [Figure 4]. We corroborate their results with the same 108/109 filtered zircon ages with ages ranging  
484 between  $2418 \pm 26$  Ma and  $587 \pm 16$  Ma. Ages younger than  $\sim 660$  Ma are unexpected and likely have  
485 suffered from some alteration to the geochronometric systems, with all ages younger than this showing  
486 moderate levels of discordance when taking the  $^{207}\text{Pb}/^{206}\text{Pb}$  age into account. There are major age  
487 populations ca. 1520 Ma and ca. 1140 Ma, with a minor population ca. 660 Ma. There is a large break in the  
488 population spectra between ca. 1060 Ma and ca. 680 Ma. Only one zircon has an age greater than ca. 1900  
489 Ma.

490 4.3.3. *Tapley Hill Formation*

491 Sample W16-10 [Figure 4] of Shahin (2016) was erroneously published as part of the Bolla Bollana Tillite in  
492 Cox et al. (2018). The 75/100 filtered zircon ages range between  $2687 \pm 50$  Ma and  $654 \pm 13$  Ma forming  
493 major population peaks at ca. 1680 Ma, ca. 1560 Ma, and ca. 1180 Ma and two minor peaks at ca. 1020 Ma  
494 and ca. 850 Ma. Only three zircons have ages greater ca. 1860 Ma and only two have ages less than ca. 840  
495 Ma.

496 4.3.4. *Amberooona Formation*

497 WR17 [Figure 4] is a new sample published in this study collected within the Willouran Ranges from the  
498 Amberooona Formation. It had a low zircon yield resulting in only 14/20 filtered zircon ages ranging between  
499  $1695 \pm 19$  Ma and  $964 \pm 9$  Ma. Five populations are present within this limited data at ca. 1690 Ma, ca. 1560  
500 Ma, ca. 1300 Ma, ca. 1160 Ma, and ca. 970 Ma.

501 4.3.5. *Wilmington Formation*

502 Data for the Wilmington Formation come from two samples. One sample was published by Ireland et al.  
503 (1998) (Ireland98\_C) from the Marino Arkose member of the Wilmington Formation sampled near Hallett  
504 Cove in Adelaide, and the second is a new sample (PR5) sampled from Pichi Richi Pass [Figure 1, Figure 4].  
505 The 94/129 filtered zircon ages range between  $2438 \pm 23$  Ma and  $655 \pm 34$  Ma, with major population peaks  
506 at ca. 1160 Ma and ca. 1030 Ma. Minor population peaks of zircon ages occur at ca. 1880 Ma, ca. 1680 Ma,



507 ca. 1570 Ma, and ca. 670 Ma. Only two zircon ages are greater than ca. 2000 Ma.

#### 508 4.3.6. *Trezona Formation*

509 Rose et al. (2013) published one sample from the Trezona Formation (CR-09) in the North Flinders Ranges  
510 [Figure 1, Figure 4]. The 119/119 filtered zircon ages range from  $2396 \pm 10$  Ma to  $674 \pm 11$  Ma, with a major  
511 peak at ca. 1200 Ma and minor population at ca. 1740 Ma.

#### 512 4.3.7. *Yaltipena Formation*

513 Rose et al. (2013) published one sample from the Yaltipena Formation (CR-04) in the South Flinders Ranges  
514 [Figure 1, Figure 4]. The 71/71 filtered zircon ages range between  $2818 \pm 10$  Ma and  $652 \pm 13$  Ma with major  
515 population peaks at ca. 1620 Ma and ca. 1180 Ma, and minor population peaks at ca. 885 Ma and ca. 680  
516 Ma. There are only three zircon ages greater than 2000 Ma. Only two zircons have ages greater than ca. 1820  
517 Ma and only three are younger than ca. 1080 Ma.

#### 518 4.3.8. *Whyalla Sandstone*

519 Five samples from three locations (CR-12, CR-13 and CR-14) were published by Rose et al. (2013) from the  
520 Whyalla Sandstone of the Stuart Shelf [Figure 3, Figure 4]. The 561/565 filtered zircon ages range from  $3061$   
521  $\pm 46$  Ma to  $641 \pm 6$  Ma, with major population peaks at ca. 1740 Ma and ca. 1590 Ma, and a minor  
522 population peak at 1180 Ma. There is also a small population of zircon ages at ca. 2480 Ma.

#### 523 4.3.9. *Elatina Formation*

524 There are twelve published samples from across the ARC for the Elatina Formation. Gehrels et al. (1996)  
525 published data for one sample (Gehrels96\_Rhynie) from the South Flinders Ranges. Rose et al. (2013)  
526 published eleven samples from the South Mount Lofty Ranges (CR-HC), the South Flinders Ranges (CR-  
527 01/Aus01, CR-01/C326-0.0, CR-02/Aus06, CR-03/Aus01, CR-03/Aus02, and CR-05/Aus10) and the North  
528 Flinders Ranges (CR-06/Aus11, CR-07/Aus12, CR-08/Aus07, CR-09/C335-31.5, CR-09/C334-560.5,  
529 CR10/Aus09, and CR11/Aus08) [Figure 4]. We add an additional two new samples from Pichi Richi Pass (PR1  
530 and PR3) bringing the total to fourteen samples with a large spatial variation. The 869/923 filtered zircon  
531 ages range from  $3564 \pm 24$  Ma to  $601 \pm 14$  Ma with a primary population peak of ca. 1180 Ma. There are  
532 secondary population peaks ca. 1780 Ma, ca. 1600 Ma, and ca. 770 Ma. The third oldest zircon in this study,

533 3564 ± 24 Ma, is found in sample CR-02/Aus06.

#### 534 4.4. *Wilpena Group*

##### 535 4.4.1. *ABC Range Quartzite*

536 The detrital zircon data for the ABC Range Quartzite come from one recently published sample from Keeman  
537 et al. (2020) (Keeman2020\_ABC) and one new sample, PR4. Both samples are from Pichi Richi Pass in the  
538 South Flinders Ranges [Figure 1, Figure 4]. The 173/182 filtered zircon ages range from 3530 ± 64 Ma to 622  
539 ± 24 Ma with a major population peak at ca. 1170 Ma and minor population peaks at ca. 1560 Ma and ca.  
540 680 Ma. Two zircons are older than 3300 Ma, with a total of five zircons having ages older than ca. 1880 Ma.  
541 The fourth oldest zircon in this dataset, 3530 ± 64 Ma is found in sample Keeman2020\_ABC.

##### 542 4.4.2. *Bunyerroo Formation*

543 Data for the Bunyerroo Formation are from two samples (WH10, WH127) in the North Flinders Ranges  
544 published by Gostin et al. (1986) [Figure 1, Figure 4]. The 20/31 filtered zircon ages range between 1481 ±  
545 36 Ma and 1041 ± 26 Ma with a single population peak ca. 1130 Ma.

##### 546 4.4.3. *Bonney Sandstone*

547 Ireland et al. (1998) published one sample (Ireland98\_D) from the Bonney Sandstone sampled in the South  
548 Flinders Ranges. We publish an additional five samples for the Bonney Sandstone from the South Flinders  
549 Ranges (PR6) and North Flinders Ranges (MWH, MWTT, CRI, and BG375) [Figure 1, Figure 4]. The 751/1101  
550 filtered zircon ages range from 3477 ± 32 Ma to 547 ± 21 Ma with major zircon age populations at ca. 1160  
551 Ma and ca. 1000 Ma. Broad minor zircon age population peaks are present at ca. 2300 Ma, ca. 1780 Ma, ca.  
552 1620 Ma, and ca. 640 Ma.

##### 553 4.4.4. *Rawnsley Quartzite*

554 Data for the Rawnsley Quartzite come from one sample (Keeman\_RQ) in the South Flinders Ranges (Keeman  
555 et al. 2020 ) [Figure 1, Figure 4], and four new samples published in this study coming from the North  
556 Flinders Ranges (CRR, BG378, and 319) and the South Flinders Ranges (PR2) [Figure 4]. The 872/1105  
557 filtered zircon ages range from 3778 ± 45 Ma to 561 ± 15 Ma with a major population peak ca. 1080 Ma. This



558 peak population is skewed toward ca. 1180 Ma, however, upon close observation there appear to be second  
559 concealed major peak ca. 1000 Ma. Broad minor population peaks are present at ca. 2300 Ma, ca 1400 Ma,  
560 and ca. 620 Ma. The second oldest zircon in this study,  $3778 \pm 45$  Ma, is found in sample CRR.

#### 561 4.4.5. *Billy Springs Formation*

562 One new sample, 58 [Figure 4], was sampled in the North Flinders Ranges from the Billy Springs Formation,  
563 the stratigraphically youngest Neoproterozoic Formation of the ARC. The 319/489 filtered zircon ages range  
564 from  $3324 \pm 25$  Ma to  $474 \pm 11$  Ma. Ages younger than ca. 540 Ma are unexpected and are all relatively  
565 discordant when considering the  $^{207}\text{Pb}/^{206}\text{Pb}$  age, while being on the limits of concordance ( $\pm 10\%$ ) using the  
566  $^{206}\text{Pb}/^{235}\text{U}$  and  $^{207}\text{Pb}/^{238}\text{U}$  ages. Thus, we consider these ages younger than ca. 540 Ma to be unreliable, and  
567 that the older  $^{207}\text{Pb}/^{206}\text{Pb}$  are more accurate ages for these zircons. Major zircon age population peaks are at  
568 ca. 1090 Ma and ca. 980 Ma, with broad minor peaks present at ca. 2500-2400 Ma, ca. 2000 Ma, ca. 1620  
569 Ma, and ca. 590 Ma.

## 570 5. Discussion

### 571 5.1. *Depositional Age Constraints*

572 This section first reviews the geochronological research, to date of publication, relevant to constraining the  
573 depositional age of Neoproterozoic formations within the Adelaide Superbasin. The appropriate raw data  
574 from published articles and theses are combined with new unpublished data and viewed as one dataset.  
575 From this large dataset we interpret maximum depositional ages for each formation using the methodology  
576 described in section 3.3.

#### 577 5.1.1. *Igneous Geochronology*

578 To date there are only two published tuff ages that provide precise absolute age constraints on deposition  
579 within the Neoproterozoic of the Adelaide Superbasin. These sit within the Rook Tuff of the Willouran Ranges  
580 [Figure 1],  $802 \pm 10$  Ma (Fanning et al. 1986) (zircon U–Pb SHRIMP), and the Wilyerpa Formation,  $663.03 \pm$   
581  $0.11$  Ma (Cox et al. 2018) (zircon U–Pb CA-ID-TIMS) of the North Flinders Ranges [Figure 1], which was  
582 initially identified and dated by Fanning and Link (2006) who produced an age of ca. 658 Ma. These two

583 points ( $802 \pm 10$  Ma &  $663.03 \pm 0.11$  Ma) constrain the basal formations of the Curdimurka Subgroup and  
584 the top formation of the Yudnamutana Subgroup, respectively.

585 In the Adelaide area of the South Mount Lofty Ranges [Figure 1], two granitic gneisses were sampled for  
586 geochronology by Preiss et al. (2008). Originally thought to be related to the Delamerian Orogeny, the Mount  
587 Crawford Granite Gneiss (Mills 1963), and the Oakbank Inlier Granitic Gneiss, yielded magmatic  
588 crystallisation ages of  $812 \pm 6$  Ma and  $856 \pm 20$  Ma for the precursor granites of each respectively. These  
589 present useful constraints on the maximum possible age of deposition for the rocks in the Adelaide area of  
590 the Adelaide Superbasin. The oldest known rock in the Adelaide Superbasin from this area, the Aldgate  
591 Sandstone, is interpreted to be at the base of the Burra Group and unconformably overlies the Mount  
592 Crawford Granite Gneiss.

593 The Koorunga Member of the Skilloogalee Dolomite contains syn-depositional volcanism, and a  
594 penecontemporaneous felsic porphyry that has been described as cross-cutting the member. Preiss et al.  
595 (2009) performed U–Pb LA-ICP-MS analysis on zircon from both the volcanoclastic siltstone of the Koorunga  
596 Member and the cross-cutting felsic porphyry yielding ages of  $787 \pm 6$  Ma and  $794 \pm 4$  Ma respectively, those  
597 authors quoted a minimum depositional age of ca. 790 Ma due to the conflicting ages. The exact relationship  
598 of this cross-cutting porphyry to the volcanoclastic siltstone within the Koorunga Member is not well explained  
599 in Preiss et al. (2009), Drexel (2009) or Drexel and McCallum (1986) and revisiting the site to view the  
600 relationship is not possible as the samples are from the Burra copper mine, which is now flooded.

601 Other igneous ages that may constrain the timing of deposition exist; however, due to uncertainty in  
602 stratigraphic relationships, large analytical uncertainty, or their unpublished nature, these are considered  
603 less reliable than the previously described ages. These are described in the following paragraphs.

604 The Wooltana Volcanics of the Arkaroola area [Figure 1] have been dated using Rb-Sr whole rock, which yield  
605 an age of  $830 \pm 50$  Ma, recalculated in Preiss (2000) from Compston et al. (1966). This isochron age has a  
606 large uncertainty. Further, the Wooltana Volcanics are unconformably overlain by the Burra Group, with the  
607 entire Curdimurka Subgroup not deposited in the Arkaroola area, suggesting a depositional hiatus in the  
608 region (Preiss 1987). Other areas of the Adelaide Superbasin have volcanic rocks that are correlated with the

609 Wooltana Volcanics as part of the Willouran Basic Province (Hillyard 1990). These include the Noranda  
610 Volcanics, the Cadlarena Volcanics, the Beda Basalt (Wade, CE et al. 2014), the Willangee Basalt, volcanic  
611 clasts within diapiric breccia, and the 'Depot Creek Volcanics', all of which are suggested as coeval to the  
612 Gairdner Dolerite,  $826 \pm 7$  Ma (Wingate et al. 1998), and the "Little Broken Hill gabbro",  $827 \pm 9$  Ma (Wingate  
613 et al. 1998), of the Gairdner Dyke Swarm (GDS). The correlative Gairdner Dolerite age of ca. 827 Ma has  
614 recently been quoted as the age of the Wooltana Volcanics (Hore 2015; Keeman et al. 2020; Mackay 2011).  
615 While there is little doubt that this association is reasonable, it does not provide a direct age of the Wooltana  
616 Volcanics and associated formations of the Willouran Basic Province. Initial correlation of the Gairdner  
617 Dolerite to the Willouran Basic Province was based on an unpublished age from the Boucaut Volcanics by the  
618 upper intercept of its uncertainty (Drexel et al. 1993). This correlation with the Boucaut Volcanics has since  
619 proven to be incorrect and is discussed later in this section. In our view, the Rb–Sr age of  $830 \pm 50$  Ma  
620 should be used for the Wooltana Volcanics, *sensu stricto*, until a more reliable age can be obtained.

621 The most dependable of the additional igneous ages is that of the Oodla Wirra Volcanics within the Nackara  
622 Arc [Figure 1]. Two SHRIMP U–Pb concordia ages were obtained for the Oodla Wirra Volcanics,  $798 \pm 5$  Ma  
623 and  $799 \pm 4$  Ma (Fabris et al. 2005), making it coeval the Rook Tuff at  $802 \pm 10$  Ma (Fanning et al. 1986).  
624 However, stratigraphic relationships are difficult to determine as no contact relationships with intact  
625 stratigraphy are observed in the field, with further field evidence suggesting that the volcanic units are blocks  
626 within a diapiric breccia (Fabris et al. 2005). Alongside petrological analysis revealing evaporite mineralogy,  
627 the two SHRIMP ages suggest that the Oodla Wirra Volcanics belong to the Curdimurka Subgroup and are  
628 equivalent to the Rook Tuff.

629 A third available dated igneous formation is the Boucaut Volcanics of the Nackara Arc [Figure 1]. Initially this  
630 formation was thought to be a stratigraphic equivalent to the Wooltana Volcanics and led to its correlation  
631 with the GDS (Wingate et al. 1998). Although the overall correlation of the GDS to the Wooltana Volcanics  
632 seems to remain true, the specific correlation of the Boucaut Volcanics to the Gairdner Dolerite and  
633 Wooltana Volcanics does not hold true. The stratigraphic relationship of the silicic Boucaut Volcanics still  
634 remains difficult to determine but is currently considered to be within the basal Burra Group, within or below

635 the Rhynie Sandstone (Preiss 2000). Two ages for the Boucaut Volcanics are mentioned in literature,  $783 \pm$   
636  $42$  Ma (Drexel et al. 1993) and  $777 \pm 7$  Ma cited in Preiss (2000). However, both ages have never been  
637 formally published with verifiable results. More recent analysis of the Boucaut Volcanics via U–Pb LA-ICP-MS  
638 on zircon is yet to be published but yields an age ca. 788 Ma (Armistead et al. in prep, pers comms). This is  
639 an important age as it potentially constrains the base of the Burra Group thereby providing minimum age for  
640 the division of the syn-rift evaporitic clastic, carbonate sediments, and volcanic lithologies of the Callanna  
641 Group from the proximal marine to marine formations of the overlying Burra Group. Current geochronology  
642 suggests that the Boucaut Volcanics are equivalent to the volcanics within the Kooringa Member of the  
643 Skillogalee Dolomite and would therefore constrain the basal formations of the Mundallio Subgroup. An  
644 alternative explanation is that the Boucaut Volcanics are indeed at the base of or within the Rhynie  
645 Sandstone as is currently considered. However, this would require a compression of stratigraphy and revision  
646 of the Emeroo and Mundallio Subgroups. Detailed mapping of the type-section area is required to clarify the  
647 exact stratigraphic position of the Boucaut Volcanics. High precision CA-ID-TIMS geochronology of the  
648 Kooringa Member, Boucaut Volcanics, Rook Tuff and Oodla Wirra Volcanics would prove fruitful in identifying  
649 their true chronological relationships to each other.

650 A rhyolite in the Mount Arrowsmith Volcanics, which form a younger silicic igneous formation within the  
651 Koonenberry Belt [Figure 1] (New South Wales), has been dated by SHRIMP U–Pb zircon at  $585.5 \pm 3.2$  Ma  
652 (Black 2007). This provides an excellent constraint within the Neoproterozoic–Cambrian Kara Formation of  
653 the Grey Range Group. The Grey Range Group is interpreted as the stratigraphic equivalent of the Farnell  
654 Group (Greenfield & Mills 2010), the uppermost division of the New South Wales component of the Adelaide  
655 Supergroup (Cooper, PF et al. 1974). The correlation to the South Australian Adelaidean sequences was last  
656 updated in Sheibner and Basden (1998) based upon the prior literature, however, this literature includes now  
657 superseded stratigraphic grouping and nomenclature. The Mount Arrowsmith Volcanics are tentatively  
658 correlated to the position of the Aruhna Subgroup within the Wilpena Group in the South Australian portion  
659 of the Adelaide Superbasin. This correlation is based upon the age of the Yarloo Shale described later in  
660 section 5.1.2, and research of stratigraphic relationships based on previous literature (Cooper, PF et al.

661 1974; Drexel et al. 1993; Powell et al. 1994; Preiss 1987; Preiss & Cowley 1999; Preiss et al. 1998; and  
662 references therein). The age of the Mount Arrowsmith Volcanics is not presented in Figure 6, Figure 7, or  
663 Table 2 due to uncertainty in the correlation at this stage; however, a detailed, updated stratigraphic  
664 correlation of the Adelaidean system for South Australia and New South Wales is linked in *Data Availability*.  
665 There have been other attempts at dating the basic igneous formations of the Adelaide Superbasin, with little  
666 success. The Beda Volcanics of the Stuart Shelf, now Beda Basalt (Wade, CE et al. 2014), has yielded Rb–Sr  
667 whole rock isochron ages of  $697 \pm 70$  Ma (Webb & Hörr 1978) and later  $1076 \pm 34$  Ma (Webb & Coats 1980).  
668 Webb and Coats (1980) discounted the younger age based on Rb–Sr whole rock isochron ages of the Tapley  
669 Hill Formation and the now superseded 'Willochra Subgroup' (the Upalinna and Yerelina subgroups contain  
670 what was the Willochra) that both overlie the Beda Basalt. However, the isochron ages for the Tapley Hill  
671 Formation and 'Willochra Subgroup' themselves are now considered inaccurate as is discussed later in  
672 section 5.1.2. Neither of the ages for the Beda Basalt have been substantiated. Significant doubts about  
673 these ages exist because of the strong geochemical and petrological affinities to the other basic volcanics of  
674 the Willouran Basic Province (Crawford & Hillyard 1990; Gum 1987; Hillyard 1990; Wade, CE et al. 2014;  
675 Woodget 1987) and thus the uncertainty regarding the accuracy of these ages forces us to consider them  
676 unreliable.

677 The early Cambrian Heatherdale Shale of the Normanville Group within the South Mount Lofty Ranges [Figure  
678 1] contains a tuff that was analysed via U–Pb SHRIMP yielding a zircon age of  $526 \pm 4$  Ma (Cooper, JA et al.  
679 1992), this was later revised to  $522 \pm 2$  Ma (Jenkins et al. 2002), and then subsequently to  $514.98 \pm 0.22$   
680 Ma (Betts et al. 2018), providing an absolute minimum age for deposition of the Heysen Supergroup in the  
681 southern Adelaide Superbasin. The Heatherdale Shale lies at the top of the Normanville Group, and as such  
682 the actual minimum age for deposition the Heysen Supergroup is likely much older than  $514 \pm 0.22$  Ma and  
683 is consistent with the palaeontological data (Betts et al. 2018; Jenkins et al. 2002). In addition, Betts et al.  
684 (2018) determined zircon TIMS ages of  $515.38 \pm 0.13$  Ma,  $514.56 \pm 0.13$  Ma, and  $514.46 \pm 0.13$  Ma, from  
685 three tuffs in the stratigraphically equivalent Mernmerna Formation of the Arrowie Basin.

686 The advancement of modern geochronological techniques, an improved understanding of geochronological





687 systems, and the discovery of small intermediate to felsic volcanic sequences may provide a significantly  
688 greater understanding of the absolute geochronological constraints of the Adelaide Superbasin in the future.

### 689 5.1.2. *Other Geochronological Techniques*

690 There have been several attempts to date sedimentary rocks of the Adelaide Superbasin via whole rock  
691 methods with varying success. The oldest formation for which this has been attempted is the Tapley Hill  
692 Formation of the Nepouie Subgroup, Umberatana Group. Webb and Coats (1980) analysed samples of Tapley  
693 Hill Formation and Willochra Subgroup from the Stuart Shelf via Rb–Sr whole rock geochronology, yielding  
694 isochron ages of  $750 \pm 53$  Ma and  $724 \pm 40$  Ma, respectively. The  $724 \pm 40$  Ma age was altered by Webb et  
695 al. (1983) with the addition of a sixth Rb–Sr whole rock sample to  $686 \pm 59$  Ma. However, Webb et al. (1983)  
696 noted that the sixth sample was lithologically different from the original five and the legitimacy of its  
697 inclusion was questioned. More recent work by Kendall et al. (2006) using Re–Os whole rock geochronology  
698 on black shales of the Tindelpina Sale Member (basal Tapley Hill Formation) yielded a pooled age of  $643 \pm$   
699  $2.4$  Ma from both the Stuart Shelf ( $647 \pm 10$  Ma) and the Adelaide Rift Complex ( $645.1 \pm 4.8$  Ma). Alongside  
700 the Rook Tuff age of Fanning et al. (1986), this cast the original ages for the Tapley Hill Formation into doubt.  
701 The Re–Os age was suggested to reflect “basin-wide post-depositional homogenization of the Os isotopic  
702 composition of the Tindelpina Shale” by Mahan et al. (2010) who obtained an age via Th–U–total Pb age of  
703 authigenic monazite of  $680 \pm 23$  Ma for the Enorama Shale. The recent age of  $663.03 \pm 0.11$  Ma obtained by  
704 Cox et al. (2018) for a tuff in the Wilyerpa Formation, which is stratigraphically below the Tapley Hill  
705 Formation, confirms that the ca. 750 Ma and ca. 724 Ma ages are indeed inaccurate. It also suggests that the  
706  $643 \pm 2.4$  Ma (Kendall et al. 2006) Re–Os age is likely to be closer to the true depositional age. However, this  
707 Re–Os age would require a significant hiatus or condensation in deposition from the end of the Sturtian  
708 Glaciation, ca. 663 Ma (Cox et al. 2018), conflicts with the  $657.2 \pm 5.4$  Ma (Kendall et al. 2006) Re–Os whole  
709 rock age obtained for the Aralka Formation, a purportedly coeval formation from the Amadeus Basin  
710 (Edgoose 2013; Preiss 1987), and conflicts with some estimates for the onset of the Marinoan Glaciation  
711 (Hoffman et al. 2017; Rooney et al. 2020). In light of this tuff age, the estimate of minimum depositional age  
712 for the Enorama Shale,  $680 \pm 23$  Ma (Mahan et al. 2010), is also not considered accurate as the Enorama



713 Shale is positioned stratigraphically above (approximately 3 km up sequence) the Tindelpina Shale Member  
714 and Wilyerpa Formation.

715 Further attempts at other geochronology have had varying success, with Webb et al. (1983) reporting Rb–Sr  
716 whole rock isochron ages for the Tregolana Shale Member (prev. Woomera Shale) of the Stuart Shelf,  $676 \pm$   
717  $200$  Ma, the stratigraphically equivalent Brachina Formation of the Adelaide Rift Complex,  $601 \pm 68$  Ma, and  
718 the stratigraphically lower Angepena Formation  $618 \pm 136$  Ma. Compston et al. (1987), later pooled the ages  
719 for the Tregolana Shale Member and Brachina Formation to yield an age of  $609 \pm 64$  Ma for the Brachina  
720 Formation that is broadly supported by more recent geochronological constraints. Compston et al. (1987),  
721 also pooled the Angepena Formation age and earlier Tapley Hill Formation (Webb et al. 1983) age to yield an  
722 age of  $713 \pm 38$  Ma for the middle Umberatana Group. Based upon more recent work and the data presented  
723 in this paper, the pooled and individual ages for the Brachina Formation are within uncertainty of the  
724 expected depositional age. However, this pooled age is not considered to be useful, as the two formations  
725 are not stratigraphic equivalents and the age for the Tapley Hill Formation has been confirmed inaccurate.  
726 Haines et al. (2004), undertook a large case study using detrital muscovite in the Adelaide Superbasin for  
727 provenance investigations discussed in section 5.2. Aside from two clearly reset samples, most of the  
728 detrital muscovite in the samples yielded ages significantly older than inferred depositional ages for the  
729 Neoproterozoic sedimentary rocks analysed. Their exception to this was the Bonney Sandstone that yielded  
730 a detrital muscovite grain with an age of  $601 \pm 17$  Ma, which (Haines et al. 2004) suggested may approach  
731 the true age of deposition.

732 An equivalent of the Bunyeroo Formation in the Adelaide Rift Complex is the Yarloo Shale of the Stuart Shelf  
733 that yielded a model-3 Rb–Sr isochron age of  $588 \pm 35$  Ma (Webb 1980) with an MSWD of 8.7. This is a Rb–  
734 Sr whole rock age and was noted by the author that its significance could only be verified by the dating of  
735 other rocks from the same stratigraphic level on the Stuart Shelf and it has since been suggested that three  
736 of the seven samples making the isochron are from the basal parts of the Wonoka Formation (Compston et  
737 al. 1987), nonetheless it provides a guiding constraint where there otherwise would not be one. Modern in-  
738 situ Rb–Sr LA-QQQ-MS and authigenic titanite methods are likely to provide much greater clarification and

739 accuracy of depositional ages for suitable sedimentary rocks within the Adelaide Superbasin.

### 740 5.1.3. Previous Detrital Zircon Geochronology

741 To date, there have been seven studies that have published detrital zircon data from the Adelaide  
742 Superbasin. The first, Compston et al. (1987), undertook a study to show that a particular tuff-like layer in  
743 the Bunyeroo Formation was not formed from volcanic detritus contemporaneous with sedimentation, and is  
744 actually an ejecta blanket associated with the Acraman impact (Gostin et al. 1986; Williams 1986). Of  
745 relevance, this study provides two samples (WH10, WH127, Figure 4) from detrital layers of the Bunyeroo  
746 Formation for which they quoted a depositional age of  $593 \pm 32$  Ma. The next study to produce detrital zircon  
747 data was conducted almost ten years later by Gehrels et al. (1996) who were investigating the provenance of  
748 the Alexander terrane in Alaska. This study published two samples from the Adelaide Superbasin in the  
749 Elatina Formation and the Rhynie Sandstone [Figure 4]. Following this, Ireland et al. (1998), undertook a  
750 study to investigate the development of the early Palaeozoic Pacific margin of Gondwana using detrital zircon  
751 geochronology from samples across the Delamerian Orogen. Ireland et al. (1998) collected nine samples  
752 from the Adelaide Superbasin [Figure 4], with four from Neoproterozoic formations; the Niggly Gap Beds, the  
753 Mitcham Quartzite, the Marino Arkose Member, and the Bonney Sandstone. No maximum depositional ages  
754 were quoted in Gehrels et al. (1996) or Ireland et al. (1998). A further eleven years later Preiss et al. (2009)  
755 published their study on the Kooringa Member of the Skilloogalee Dolomite in which they defined the member  
756 and investigated the age of the host formation of the Burra copper orebody [Figure 1]. This study provided  
757 two samples from a volcanoclastic siltstone within the Kooringa Member and a penecontemporaneous  
758 porphyry. Rose et al. (2013), conducted a detailed study of the Marinoan glaciation in South Australia  
759 producing a highly focussed dataset of 20 samples [Figure 4] from the Trezona Formation, the Yaltipena  
760 Formation, the Elatina Formation, and the Whyalla Sandstone. No maximum depositional ages were quoted  
761 by Rose et al. (2013). A study investigating the timing of the end of the Sturtian Glaciation by Cox et al.  
762 (2018) published a tuff age from the Wilyerpa Formation, that is described earlier in this section, and two  
763 detrital samples (W16-09 & W16-10, Figure 4) from Shahin (2016). One of these samples—W16-10—is  
764 erroneously published by Cox et al. (2018) as belonging to the Bolla Bollana Tillite rather than the Tapley Hill



765 Formation from which it was sampled. The most recent publication on detrital geochronology in the Adelaide  
766 Superbasin by Keeman et al. (2020) is a comprehensive study that reprocesses samples from Ireland et al.  
767 (1998) and publishes new data from the Gilbert Range Quartzite, Sturt Tillite, Appila Tillite, Brachina  
768 Formation, ABC Range Quartzite, Rawnsley Quartzite, and several Cambrian formations. While this study is  
769 extensive and provides much needed hafnium isotope data, the supplementary dataset available with the  
770 publication is incomplete. Additionally, several detrital zircon studies have been completed as research  
771 projects (Drabsch 2016; Job 2011; Shahin 2016; Mackay 2011), adding a significant amount of detrital  
772 zircon data that had not yet been formally published.

#### 773 5.1.4. *Detrital Zircon Maximum Depositional Ages*

774 This section interprets and discusses detrital zircon maximum depositional ages (MDAs) quoted as the  
775 *preferred MDA* from Table 2 for the each of the Neoproterozoic Formations in this study of the Adelaide  
776 Superbasin, in stratigraphic order of oldest to youngest, using the combined dataset presented in this paper.  
777 The dataset includes legacy and new data and is all subject to the statistical methods outlined in section 3.3.  
778 Only the formations from Keeman et al. (2020) with their full data available in their supplementary data are  
779 reinterpreted with our methods; these are the Gilbert Range Quartzite, the Appila Tillite, the Bonney  
780 Sandstone, and the Rawnsley Quartzite. All other MDAs from Keeman et al. (2020) are taken as is reported  
781 by those authors. However, we modify their uncertainty to two standard deviations and quote ages as whole  
782 integers. All geochronological constraints, including the MDAs described in this section are summarised in  
783 Table 2. Regions highlighted in parentheses after a formation name correspond to the areas outlined in  
784 Figure 1.

##### 785 5.1.4.1. *Callanna Group*

786 Of the 24 sedimentary formations in the Callanna Group only four have detrital zircon U–Pb data. The oldest  
787 of these, the Paralana Quartzite, is restricted to the Arkaroola area [Figure 1] and has an MDA of  $1177 \pm 28$   
788 Ma. This age is significantly older than the expected depositional age of ca. 840 Ma (Powell et al. 1994;  
789 Preiss 1987; 2000). The minimum age of deposition for the Arkaroola Subgroup is constrained by the  
790 Wooltana Volcanics,  $830 \pm 50$  Ma (Preiss 2000). There are currently no detrital zircon data from any other



791 Arkaroola Subgroup or equivalent Pintapah Subgroup (NSW), and Wendalpa Subgroup (NSW) rock. Following  
792 this, the Dome Sandstone (Willouran Ranges), the oldest rock of the Curdimurka Subgroup, has an MDA of  
793  $993 \pm 62$  Ma. This is older than the true depositional age of the Dome Sandstone as the Wooltana Volcanics  
794 (corr. Noranda Volcanics, Willouran Ranges) and Rook Tuff provide maximum and minimum limits of  
795 deposition at  $830 \pm 50$  Ma (Preiss 2000) and  $802 \pm 10$  Ma (Fanning et al. 1986) respectively. The remaining  
796 two formations of the Callanna Group with detrital zircon data are the Niggly Gap Beds (North Mount Lofty  
797 Ranges) and Recovery Sandstone (Willouran Ranges). The Rook Tuff provides a maximum age constraint of  
798  $802 \pm 10$  Ma (Fanning et al. 1986) and the Koorunga Member and Boucaut Volcanics provide a minimum age  
799 constraint of ca. 790 Ma (Preiss et al. (2009); Armistead et al. in prep, pers comms) for the Niggly Gap Beds  
800 and Recovery Sandstone. The Niggly Gap Beds have an MDA of  $1616 \pm 34$  Ma, well beyond the range for true  
801 depositional age. The Recovery Sandstone has no zircon within 2% of concordance and thus we do not quote  
802 an MDA for the formation. There are limited data available for both the Niggly Gap Beds (n=30/50), and  
803 Recovery Sandstone (n=2/71). There are currently no detrital zircon data from any other Curdimurka  
804 Subgroup rock.

#### 805 5.1.4.2. *Burra Group*

806 Of the 36 named formations within the Burra Group, eight have detrital zircon U–Pb geochronology data. In  
807 the South Mount Lofty Ranges [Figure 1] the Burra Group is constrained to a being deposited after  $812 \pm 6$   
808 Ma [Figure 6] by the Mount Crawford Granite Gneiss (Preiss et al. 2008) that directly, but unconformably  
809 underlies the oldest Burra Group formation in the region. The Emeroo Subgroup is further constrained to a  
810 minimum age of ca. 790 Ma by penecontemporaneous volcanism within the Koorunga Member of the  
811 Skillogalee Dolomite (Preiss et al. 2009). Within the Emeroo Subgroup there are five named formations with  
812 detrital zircon geochronology data. The oldest of the named formations, the Top Mount Sandstone (Willouran  
813 Ranges) and correlative Humanity Seat Formation (Arkaroola Area), and Rhynie Sandstone (North Mount  
814 Lofty Ranges) have MDAs of  $841 \pm 21$  Ma,  $1053 \pm 114$  Ma, and  $1513 \pm 26$  Ma, respectively. The Blue Mine  
815 Conglomerate (Arkaroola Area) has an MDA of  $1106 \pm 85$  Ma and the Copley Quartzite (North Flinders  
816 Ranges) has an MDA of  $1129 \pm 51$  Ma. These Emeroo Subgroup MDAs are much older than the true

817 depositional age. The three formations with detrital zircon geochronology data in the Burra Group are the  
818 Skillogalee Dolomite, (MDA:  $789 \pm 9$  Ma), the Mitcham Quartzite (MDA  $1053 \pm 42$  Ma, South Mount Lofty  
819 Ranges), and the Gilbert Range Quartzite (MDA  $731 \pm 34$  Ma, North Mount Lofty Ranges). The Skillogalee  
820 Dolomite MDA is within uncertainty of true depositional age as shown by the age for penecontemporaneous  
821 volcanism within the Kooringa Member of the Skillogalee Dolomite, ca. 790 Ma (Preiss et al. 2009). The  
822 Mitcham Quartzite MDA is an overestimate of true depositional age and the Gilbert Range Quartzite MDA is  
823 likely close to true depositional age (pre-Sturtian Glaciation), with estimates for the onset of the Sturtian  
824 Glaciation ca. 715 Ma (Hoffman et al. 2017).

#### 825 5.1.4.3. *Umberatana Group*

826 There are eight formations of the total 38 named formations within the Umberatana Group that have detrital  
827 zircon U–Pb geochronology data. The Yudnamutana Subgroup glacial sedimentary rocks are constrained to a  
828 minimum age of ca. 663 Ma by a tuff layer within the overlying Wilyerpa Formation (Cox et al. 2018). Detrital  
829 zircon data are available from the Bolla Bollana, Sturt and Appila Tillites. The MDA for the Bolla Bollana Tillite  
830 (North Flinders Ranges) is  $673 \pm 19$  Ma, this differs from that in Cox et al. (2018) as it excludes sample W16-  
831 10 which has been reassessed as being from the lowermost Tapley Hill Formation (Shahin 2016). For the  
832 Appila Tillite (South Flinders Ranges), we use the youngest population age of  $667 \pm 6$  Ma, as the youngest  
833 single grain is below the minimum constraint provided by the Wilyerpa Tuff and has potentially suffered from  
834 modern lead loss, a point also made by Keeman et al. (2020). For the Sturt Tillite we use the MDA quoted by  
835 Keeman et al. (2020) of  $714 \pm 28$  Ma (YSG) as their supplementary data for the Sturt Tillite is incomplete.  
836 The MDAs for the Yudnamutana Subgroup glacial rocks are consistent with estimates for the duration of the  
837 Sturtian Glaciation ca. 715–660 Ma (Cox et al. 2018; Hoffman et al. 2017; Rooney et al. 2020). The Tapley  
838 Hill Formation has an MDA of  $654 \pm 13$  Ma, this is from sample W16-10 of (Shahin 2016) and is consistent  
839 with the timing of Sturtian deglaciation. Within the Upalinna Subgroup there are detrital zircon data for the  
840 Wilmington Formation, Amberoona Formation, Trezona Formation, and Yaltipena Formation. Respectively,  
841 the MDAs of these formations are  $688 \pm 8$  Ma,  $1110 \pm 71$  Ma,  $674 \pm 11$  Ma, and  $662 \pm 20$  Ma. Keeman et al.  
842 (2020) quote a youngest mean weighted age for  $654 \pm 13$  Ma for the Marino Arkose Member of the



843 Wilmington Formation with reprocessed data from Ireland et al. (1998). However, we cannot verify this from  
844 their supplementary dataset. With the exception of the Amberoona Formation, MDAs of these Upalinna  
845 Subgroup rocks are approaching the estimated true depositional ages as constrained by the Sturtian  
846 deglaciation ca. 663 Ma (Cox et al. 2018) and estimated onset of the Marinoan Glaciation ca. 650–640 Ma  
847 (Hoffman et al. 2017). The Amberoona Formation only has extremely limited data available (n=14). The  
848 remaining two formations of the Umberatana Group with detrital zircon geochronology data are the Elatina  
849 Formation (MDA  $671 \pm 52$  Ma) and the coeval Whyalla Sandstone (MDA  $641 \pm 6$  Ma) of the Stuart Shelf, both  
850 are within uncertainty of their expected true depositional ages during the Marinoan glaciation ca. 650–635  
851 Ma (Hoffman et al. 2017).

#### 852 5.1.4.4. *Wilpena Group*

853 Six of the fifteen formations of the Wilpena Group have detrital zircon U–Pb geochronology data. Keeman et  
854 al. (2020) quote results from the Brachina Formation, however, these data are missing from their  
855 supplementary dataset and no MDA is quoted. The other only other Sandison Subgroup formation with  
856 detrital zircon U–Pb age data are in the ABC Range Quartzite and has an MDA of  $630 \pm 16$  Ma. The MDA of  
857 the ABC Range Quartzite is likely within uncertainty of the true depositional age for this formation and is  
858 compatible with estimates for the end of the Marinoan Glaciation at ca. 635 Ma (Hoffman et al. 2017). The  
859 Bunyeroo Formation of the Aruhna Subgroup has an MDA of  $1041 \pm 26$ , significantly older than true  
860 depositional age. Limited data (n=20/31) available for this formation. In this publication we add a substantial  
861 amount (>1000 for each formation) of new data for the Bonney Sandstone and the Rawnsley Quartzite of the  
862 Pound Subgroup. The Rawnsley Quartzite is most famously known for the fossils of Ediacara fauna that it  
863 preserves (Droser & Gehling 2015; Gehling & Droser 2012; Glaessner 1959; Sprigg 1948). Here we quote  
864 conservative ages of  $579 \pm 32$  Ma and  $570 \pm 23$  Ma for the Bonney Sandstone and Rawnsley Quartzite,  
865 respectively. The MDA of the Rawnsley Quartzite is within uncertainty, and therefore compatible with  
866 estimates for the ages of various Ediacara fauna ca. 575–541 Ma (Grazhdankin 2004). The youngest  
867 Neoproterozoic formation of the central Adelaide Rift Complex is the Billy Springs Formation, for which we  
868 add a substantial amount of data (n>300) and quote an MDA of  $564 \pm 25$  Ma. This is again, likely to be within



869 uncertainty of the true depositional age of the formation.





**Table 2** - Summary of Adelaide Superbasin (Neoproterozoic) Geochronology with Maximum Depositional Ages (MDA)

Formation	Region	n zircon (filtered)	Auto MDA (Ma) YSG^	<sup>206</sup> Pb/ <sup>238</sup> U Age of YSG (Ma)	<sup>207</sup> Pb/ <sup>235</sup> U Age of YSG (Ma)	<sup>207</sup> Pb/ <sup>206</sup> Pb Age of YSG (Ma)	MDA (Ma) YPA* (n; MSWD)	Depositional Age (Ma) (Syn-MDA & (Ma) , Min.)	Preferred (Ma)	Geochronology Method	Original Data Source
Billy Springs Formation ( <i>Npi</i> )	North Flinders Ranges	319	553 ± 15	553 ± 15	564 ± 25	612 ± 123		<b>564 ± 25</b>	LA-ICP-MS Detrital Zircon	This study	
Rawnsley Quartzite ( <i>Npr</i> )	Flinders Ranges	872	562 ± 15	562 ± 15	570 ± 23	603 ± 115	583 ± 8 (5; 0.68)	<b>570 ± 23</b>	LA-ICP-MS Detrital Zircon	This study; Keeman et al. (2020)	
Bonney Sandstone ( <i>Npb</i> )	Flinders Ranges	751	568 ± 18	568 ± 18	579 ± 32	623 ± 155	587 ± 10 (3; 0.75)	<b>579 ± 32</b>	LA-ICP-MS Detrital Zircon	Ireland et al. (1998); this study	
Yarloo Shale ( <i>Nwy</i> )	Stuart Shelf							588 ± 35	Rb-Sr Whole Rock	Webb (1980)	
Bunyeroo Formation ( <i>Nwb</i> )	North Flinders Ranges	20	1041 ± 26			1041 ± 154		<b>1041 ± 26</b>	SHRIMP Detrital Zircon	Compston et al. (1987)	
ABC Range Quartzite ( <i>Nsa</i> )	South Flinders Ranges	173	622 ± 24	622 ± 24	630 ± 44	662 ± 208	645 ± 6 (8, 0.77)	<b>630 ± 16</b>	LA-ICP-MS Detrital Zircon	This study; Keeman et al. (2020)	
Brachina Formation ( <i>Nsb</i> )			630 ± 16	630 ± 16	629 ± 28	626 ± 140		609 ± 64	LA-ICP-MS Detrital Zircon	Compston et al. (1987)	
Whyalla Sandstone ( <i>Neh</i> )	Stuart Shelf	561	641 ± 6	617 ± 11	624 ± 17	641 ± 6		<b>641 ± 6</b>	LA-ICP-MS Detrital Zircon	Rose et al. (2013)	
Elatina Formation ( <i>Nee</i> )	Flinders Ranges South Mount Lofty Ranges	896	652 ± 13	652 ± 13	656 ± 15	671 ± 52	662 ± 5 (8; 0.12)	<b>671 ± 52</b>	LA-ICP-MS Detrital Zircon	Gehrels et al. (1996); Rose et al. (2013); this study	
Yaltipena Formation ( <i>Nil</i> )	South Flinders Ranges	71	652 ± 13	662 ± 20	659 ± 30	652 ± 13	662 ± 8 (3; 0.71)	<b>662 ± 20</b>	LA-ICP-MS Detrital Zircon	Rose et al. (2013)	
Trezona Formation ( <i>Niz</i> )	North Flinders Ranges	119	674 ± 11	674 ± 11	670 ± 25	650 ± 16		<b>674 ± 11</b>	LA-ICP-MS Detrital Zircon	Rose et al. (2013)	
Wilmington Formation ( <i>Niw</i> )	South Mount Lofty Ranges	94	655 ± 34	655 ± 34		666 ± 614	688 ± 8 (4; 0.99)	<b>688 ± 8</b>	LA-ICP-MS Detrital Zircon	Ireland et al. (1998); this study	
Enorama Shale ( <i>Nie</i> )	North Flinders Ranges							680 ± 23	Electron Microprobe Authigenic Monazite	Mahan et al. (2010)	
Amberooona Formation ( <i>Nib</i> )	North Flinders Ranges (Willouran Ranges)	14	1090 ± 36	1090 ± 36		1110 ± 71		<b>1110 ± 71</b>	LA-ICP-MS Detrital Zircon	This study	



**Table 2** - Summary of Adelaide Superbasin (Neoproterozoic) Geochronology with Maximum Depositional Ages (MDA)

Formation	Region	n zircon (filtered)	Auto MDA (Ma) YSG <sup>^</sup>	<sup>206</sup> Pb/ <sup>238</sup> U Age of YSG (Ma)	<sup>207</sup> Pb/ <sup>235</sup> U Age of YSG (Ma)	<sup>207</sup> Pb/ <sup>206</sup> Pb Age of YSG (Ma)	MDA (Ma) YPA* (n; MSWD)	Depositional Age (Ma) (Syn-MDA <sup>&amp;</sup> , Min.)	Preferred (Ma)	Geochronology Method	Original Data Source
Tapley Hill Formation ( <i>Nnt</i> )	North Flinders Ranges	75	654 ± 13	654 ± 13		640 ± 87			<b>654 ± 13</b>	LA-ICP-MS Detrital Zircon	Shahin (2016)
Tindelpina Shale Member ( <i>Nntt</i> )	North Flinders Ranges							643 ± 2.4		Re-Os Whole Rock	Kendall et al. (2006)
Tuff in Wilyerpa ( <i>Nyw</i> )	North Flinders Ranges							663 ± 0.11		CA-ID-TIMS Igneous Zircon	Cox et al. (2018)
Appila Tillite ( <i>Nya</i> )	South Flinders Ranges	108	638 ± 30	638 ± 30	640 ± 64	647 ± 147	667 ± 6 (7; 0.45)		<b>667 ± 6</b>	LA-ICP-MS Detrital Zircon	Keeman et al. (2020)
Bolla Bollana Tillite ( <i>Nyb</i> )	North Flinders Ranges (Willouran Ranges)	218	673 ± 19	673 ± 19		667 ± 160			<b>673 ± 19</b>	LA-ICP-MS Detrital Zircon	Shahin (2016)
Gilbert Range Quartzite ( <i>Nlg</i> )	North Mount Lofty Ranges	57	694 ± 6	694 ± 6	703 ± 16	731 ± 34			<b>731 ± 34</b>	LA-ICP-MS Detrital Zircon	Keeman et al. (2020)
Mitcham Quartzite ( <i>Nlm</i> )	South Mount Lofty Ranges	35	1053 ± 42	1053 ± 42		1033 ± 60			<b>1053 ± 42</b>	LA-ICP-MS Detrital Zircon	Ireland et al. (1998)
Skillogalee Dolomite ( <i>Nms</i> )( <i>Nmsk</i> )	North Flinders Ranges North Mount Lofty Ranges	632	782 ± 24	782 ± 24		777 ± 36	789 ± 9 (7; 0.05)	ca. 790	<b>789 ± 9</b>	LA-ICP-MS Detrital Zircon LA-ICP-MS Volcaniclastic Zircon	Drabsch (2016); Fabris et al. (2005); Mackay (2011); this study
Copley Quartzite ( <i>Noc</i> )	North Flinders Ranges	188	1129 ± 51	1129 ± 51		1110 ± 190			<b>1129 ± 51</b>	LA-ICP-MS Detrital Zircon	Drabsch (2016)
Blue Mine Conglomerate ( <i>Nou</i> )	North Flinders Ranges	76	1106 ± 85	1106 ± 85	1099 ± 30	1083 ± 85			<b>1106 ± 85</b>	LA-ICP-MS Detrital Zircon	Job (2011)
Rhynie Sandstone ( <i>Nor</i> )	North Mount Lofty Ranges	27	1512 ± 10	1513 ± 26	1513 ± 26	1512 ± 10	1518 ± 5 (3; 0.24)		<b>1513 ± 26</b>	LA-ICP-MS Detrital Zircon	Gehrels et al. (1996)
Humanity Seat Formation ( <i>Noh</i> )	North Flinders Ranges	130	1022 ± 17	1022 ± 17	1033 ± 40	1053 ± 114			<b>1053 ± 114</b>	LA-ICP-MS Detrital Zircon	Job (2011); Mackay (2011)
Top Mount Sandstone ( <i>Not</i> )	North Flinders Ranges (Willouran Ranges)	85	841 ± 21	841 ± 21	840 ± 34	790 ± 130			<b>841 ± 21</b>	LA-ICP-MS Detrital Zircon	This study



**Table 2** - Summary of Adelaide Superbasin (Neoproterozoic) Geochronology with Maximum Depositional Ages (MDA)

Formation	Region	n zircon (filtered)	Auto MDA (Ma) YSG <sup>^</sup>	<sup>206</sup> Pb/ <sup>238</sup> U Age of YSG (Ma)	<sup>207</sup> Pb/ <sup>235</sup> U Age of YSG (Ma)	<sup>207</sup> Pb/ <sup>206</sup> Pb Age of YSG (Ma)	MDA (Ma) YPA* (n; MSWD)	Depositional Age (Ma) (Syn-MDA <sup>&amp;</sup> , Min.)	Preferred (Ma)	Geochronology Method	Original Data Source
Emeroo Subgroup (undifferentiated) (No)	North Flinders Ranges (Willouran Ranges)	22	No data is within 2% of concordance							LA-ICP-MS Detrital Zircon	Mackay (2011)
Boucaut Volcanics (Nox)	Nackara Arc						ca. 788		LA-ICP-MS Igneous Zircon	Armistead et al. in prep, pers. comm.	
Mount Crawford Granite Gneiss (N- f)	South Mount Lofty Ranges						812 ± 6 Ma 856 ± 20 Ma		SHRIMP Igneous Zircon	Preiss et al. (2008)	
Recovery Formation (Nkr)	North Flinders Ranges (Willouran Ranges)	2	No data is within 2% of concordance							LA-ICP-MS Detrital Zircon	Mackay (2011)
Niggly Gap Beds (Nkn)	North Mount Lofty Ranges	30	1583 ± 48	1583 ± 48		1616 ± 34	1599 ± 10 (8, 0.11)	<b>1616 ± 34</b>	LA-ICP-MS Detrital Zircon	Ireland et al. (1998)	
Oodla Wirra Volcanics (Nkx)	Nackara Arc						798 ± 5 799 ± 4		SHRIMP Igneous Zircon	Fabris et al. (2005)	
Rook Tuff (Nkk)	North Flinders Ranges (Willouran Ranges)						802 ± 10		SHRIMP Igneous Zircon	Fanning et al. (1986)	
Dome Sandstone (Nkd)	North Flinders Ranges (Willouran Ranges)	147	993 ± 62	993 ± 62	988 ± 102	771 ± 330		<b>993 ± 62</b>	LA-ICP-MS Detrital Zircon	Mackay (2011)	
Wooltana Volcanics (Nal)	North Flinders Ranges						830 ± 50		Rb-Sr Whole Rock	Preiss (2000)	
Paralana Quartzite (Nap)	North Flinders Ranges	66	1164 ± 52 <i>1169 ± 22</i>	1164 ± 52 <i>1177 ± 28</i>	1279 ± 158	1266 ± 146 <i>1154 ± 55</i>	1171 ± 16 (3, 0.03)	<b>1177 ± 28</b>	LA-ICP-MS Detrital Zircon	Job (2011); Mackay (2011)	

<sup>^</sup>maximum depositional age from the youngest single grain preferred filtered age; <sup>\*</sup>maximum depositional age from the youngest overlapping grain population average (based on preferred age for those grains); <sup>&</sup>preferred MDA is generally the older of the <sup>206</sup>Pb/<sup>238</sup>U, <sup>207</sup>Pb/<sup>235</sup>U and <sup>207</sup>Pb/<sup>206</sup>Pb ages for the YSG, providing a conservative estimate. Ages in italics are for the next youngest grain that is overall more concordant across the three decay systems and are used in place of the YSG determined by the excel formulas. See section (statistics) for methodology



871 5.2. *Provenance*

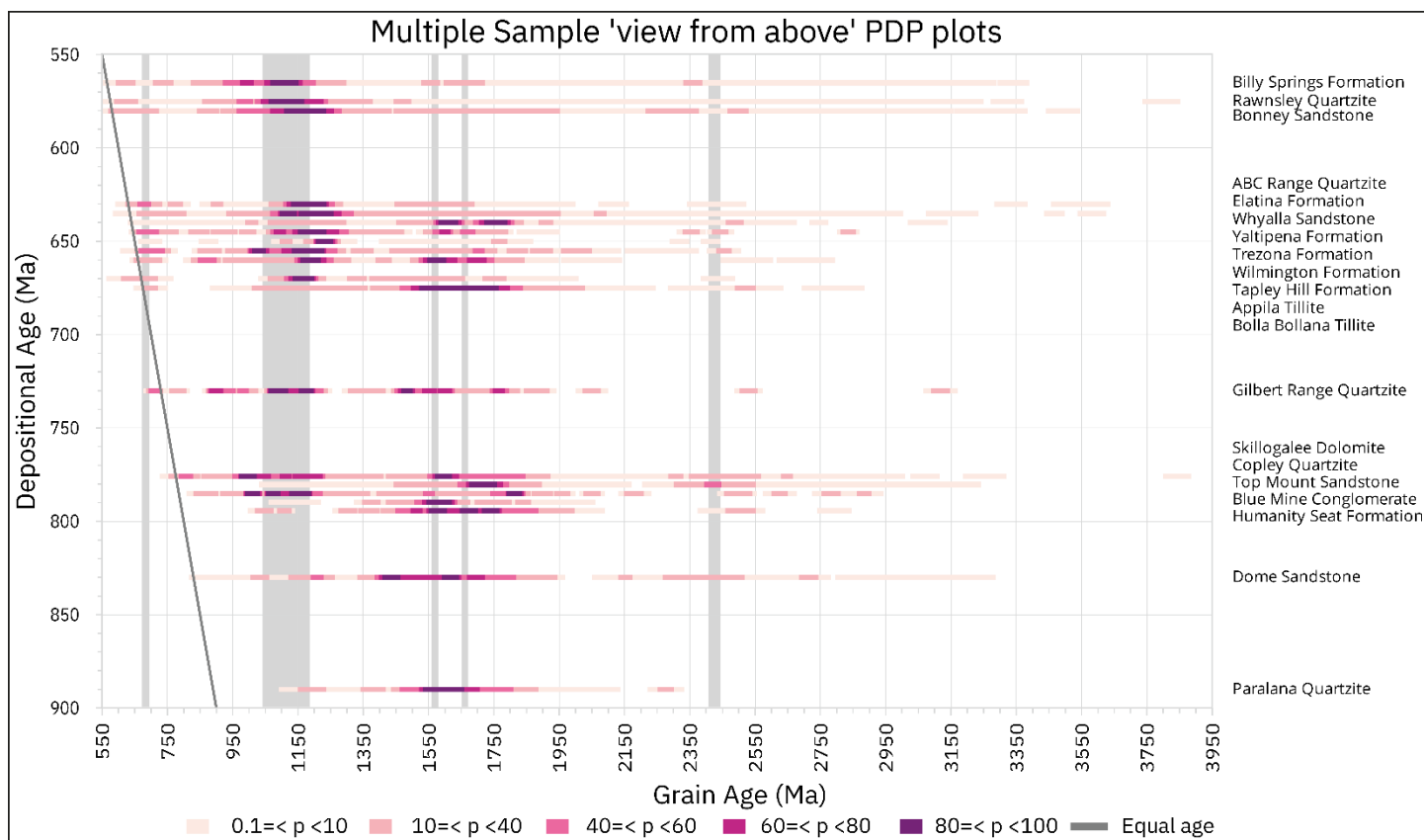
872 Previous studies that dealt with detrital zircon provenance of the sedimentary rocks in the Adelaide  
873 Superbasin (Gehrels et al. 1996; Haines et al. 2004; Ireland et al. 1998; Keeman et al. 2020; Rose et  
874 al. 2013) noted that many of the zircons yielded Mesoproterozoic ages that were broadly consistent  
875 with being sourced from the Musgrave Orogen of central Australia. Previous studies have also  
876 reached a consensus that the early Mesoproterozoic and older zircon populations found in the pre-  
877 Sturtian formations are derived from the Gawler Craton and Curnamona Province [Figure 5, Figure  
878 11]. It was also apparent that few zircons came from sources close to the age of deposition as would  
879 be expected from a non-volcanic region (Cawood et al. 2012). In addition, it was noted that time  
880 equivalent formations, such as the Whyalla Sandstone and Elatina Formation, preserved different  
881 age spectra, indicative of differing detrital source, and significant provinciality in sediment supply—at  
882 least at specific times (Rose et al. 2013). Limited Samarium–Neodymium (Sm–Nd), and Strontium  
883 (Sr) isotopic studies (Barovich & Foden 2000; Haines et al. 2009; Turner et al. 1993b) of samples  
884 within the Adelaide Superbasin and basement rocks (Gawler Craton, Curnamona Province) have  
885 noted that a heterogeneity of detritus sources is required to explain the observed Sm–Nd signatures  
886 of the formations within the Adelaide Superbasin. Turner et al. (1993b), also noted that the Sturtian  
887 glaciogenic formations yielded  $\epsilon\text{Nd}$  and  $T_{\text{DM}}$  values more similar to that of the Callanna Group and  
888 suggested this represented a transitory restriction of source region to the local basement—  
889 potentially representing the development of uplifted rift shoulders at this time. The heterogeneity of  
890 detritus sources for the Adelaide Superbasin contrasts the findings for the coeval Amadeus Basin  
891 where Barovich and Foden (2000) note a mature and homogeneous source region for clay-mica  
892 fractions of the rocks. Although not the focus of this study, the Kanmantoo Group (Kanmantoo  
893 Province, Figure 3) of the Moralana Supergroup has been suggested to access more locally derived  
894 ancient basement detritus (Gawler Craton, Figure 5), with an influx of late Neoproterozoic-early  
895 Cambrian aged zircons (Haines et al. 2009; Keeman et al. 2020; Turner et al. 1993a). Our results  
896 broadly agree with previous studies but provide a finer level of detail for the Neoproterozoic,



897 verifying the findings of most previous studies. Our latest Ediacaran samples from the Bonney  
898 Sandstone, Rawnsley Quartzite and Billy Springs Formation provide conflicting findings to those of  
899 (Keeman et al. 2020) where we observe a shift toward younger late Mesoproterozoic zircon  
900 populations away from 1180 Ma [Figure 8, Figure 9] rather than an shift toward an older 1180 Ma  
901 peak. With the corresponding increase in ca. 600 Ma and younger zircon populations [Figure 8,  
902 Figure 9] we suggest that this as the influx of a younger, southerly-derived, detritus.

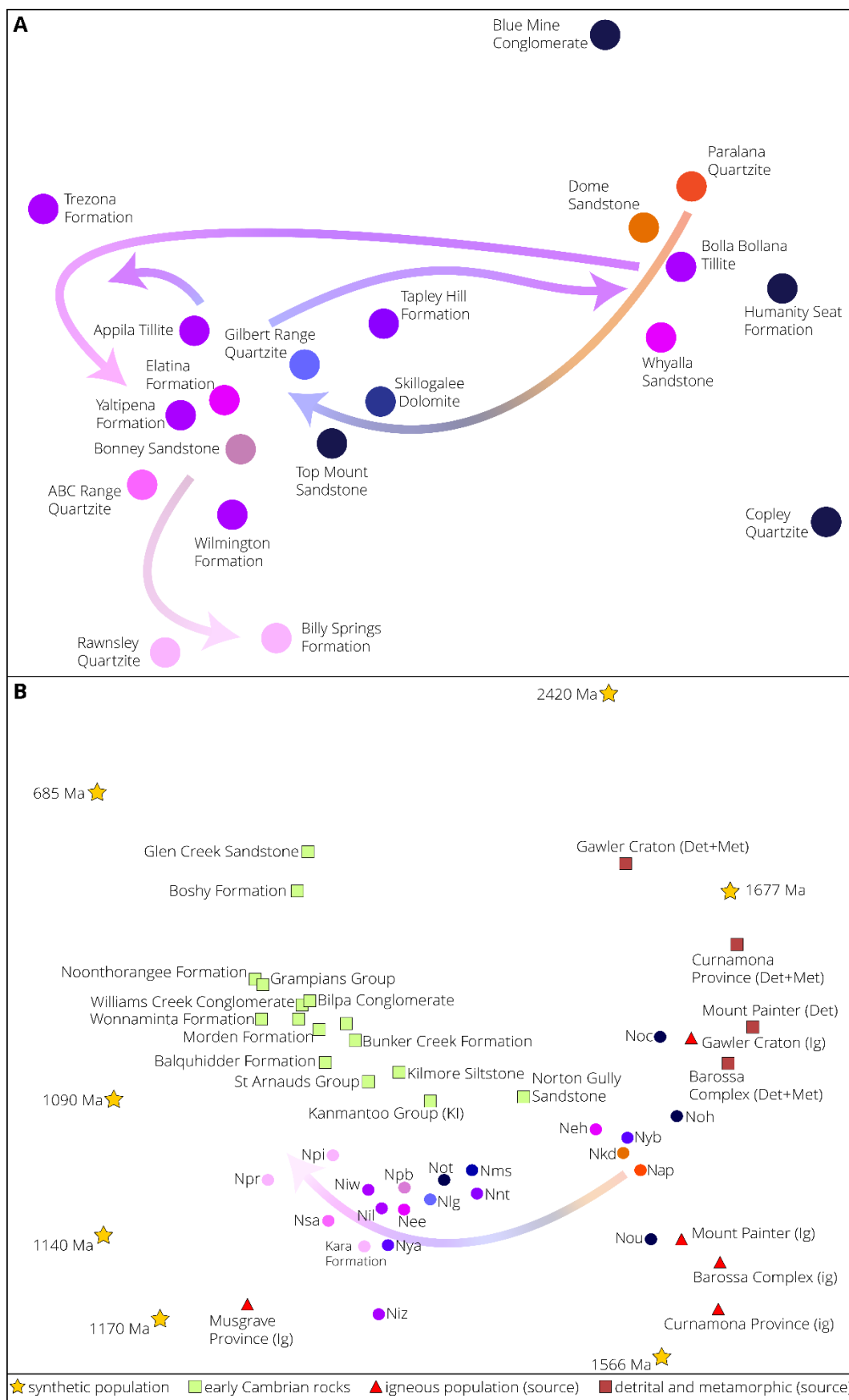
903 Compiling all legacy data and adding new detrital data allows us to analyse the most comprehensive  
904 dataset to date and identify the general trends of provenance variation within a chronostratigraphic  
905 framework. The most significant trends are identified are below.

- 906 • Younger populations become significantly more prevalent as the formations young [Figure  
907 9]. This is opposite to what might be expected if a layered sequence was progressively  
908 unroofed during deposition.
- 909 • Early Mesoproterozoic populations are less abundant in younger formations [Figure 8, Figure  
910 9]. This is coupled with a rise in dominance of late Mesoproterozoic zircons.
- 911 • There is a subtle, but notable, shift in late Mesoproterozoic zircons to younger ages away  
912 from ca. 1180 Ma [Figure 8, Figure 9].
- 913 • Coeval Sturtian glacial formations show differing age spectra [Figure 8, Figure 9, Figure 10]  
914 that we relate to heterogenous sources.
- 915 • Rare Eoarchaeon to Palaeoarchaeon zircons are more abundant in the youngest formations  
916 but coincide with more prevalent Neoproterozoic and late Mesoproterozoic populations  
917 [Figure 9].



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**Figure 9** – Multiple sample, ‘view from above’ probability density plots (PDP) of formations ( $n > 40$ ) in this study, highlighting the change in relative dominance of Proterozoic populations. Each variably coloured ‘bar’ represents a PDP of one formation; however, it is viewed from a top-down perspective. The darker colours represent higher probabilities, or peaks, of a traditional PDP. The general trend shows a decrease in probability of late Mesoproterozoic ages and a corresponding increase in Neoproterozoic ages with decreasing depositional age. It can also be seen that the late Mesoproterozoic ages show a shift in age from ca. 1700 Ma to ca. 1100 Ma, likely related to a change in provenance. The grey vertical bars highlight the centralised population peaks as established by the KDE graphs [Figure 8]; they correspond to the synthetic peaks used in the MDS plot [Figure 10]. Depositional ages are a “best guess” estimate based on the previously described age constraints and the established stratigraphic relationships. It is more important to assign depositional ages that represent the stratigraphic relationships of the formations, rather than precise true depositional ages. The order of stratigraphy is shown to the right of the Plot. Generated using FitPDF (Eglington 2018)



930 **Figure 10** – Non-metric multidimensional scaling plots of detrital zircon ( $n > 40$ ) data within the Adelaide Superbasin (A) and with  
931 synthetic peaks, some probable provenance sources and some examples from early Cambrian rocks of the Delamerian and Lachlan  
932 Orogenic belts.(B). These plots show the relative similarities of all data to each other and are intended as a visual guide. In (A)  
933 stratigraphic groups are represented by colour where orange = Callanna Group (oldest), blue = Burra Group, purple = Umberatana  
934 Group, and pink = Wilpena Group (youngest). The lightness of these colours represents time where darker shades are older formations  
935 and lighter shades are younger formations. The coloured arrows in (a) show the nuanced changes and point in the direction of  
936 stratigraphic up, i.e. arrowhead points younger, whilst the coloured arrow in (b) shows the overall trend in provenance change. Plotted  
937 using IsoplotR (Vermeesch 2018b). Axes are omitted as the algorithm used produces normalised values with no physical meaning and  
938 can be safely removed.

### 939 5.2.1. *Reliability of dataset for provenance interpretations*

940 Although a reasonable number of individual detrital ages exist for Adelaide Superbasin samples, data are  
941 concentrated within a few specific formations. Approximately 70% of the entire detrital dataset comes from  
942 just six of the 143 formation ranked units (117 named; 26 unnamed) within the Neoproterozoic of the  
943 Adelaide Superbasin. These are the Skillogalee Dolomite (~10.9%), the Elatina Formation (~15.5%), the  
944 Whyalla Sandstone (~9.7%), the Bonney Sandstone (~13%), the Rawnsley Quartzite (~15.1%), and the Billy  
945 Springs Formation (~5.5%). This limits this ability to accurately assess changes in provenance through time  
946 for the Adelaide Superbasin. More importantly, only 14 of the 26 formations with data have the statistically  
947 optimal 117 concordant analyses (Vermeesch 2004) in which it can be confidently stated that no fraction of  
948 the true population that equates to  $\geq 5\%$  of the population is missed. Further, 13 formations have less than  
949 the recommended minimum of 95 concordant analyses in which it can be stated that no fraction of the true  
950 population that equates to  $\geq 5\%$  of the population is missed. As the number of grains ( $n$ ) decreases, the  
951 dissimilarity to the true population increases and they become further statistically unreliable. As such, it is  
952 likely where  $n(\text{grains}) \leq 95$  that the observed populations are likely missing representative components of  
953 the true population and require further data. In addition, most of the data comes from the North Flinders  
954 Ranges (~63.5%), with only ~4.5% of the data coming from the Mount Lofty Ranges covering four  
955 formations, and no data from the Olary region [Figure 1, Figure 4]. This lack of spatial diversity in the dataset  
956 limits the assessment of spatial variation on provenance, a concept important in such a large basin that  
957 covers over 800 km north-south and ~400 km east-west.

### 958 5.2.2. *Archaean*

959 Archaean zircon make up only a small percentage of the dataset with no sizeable population peaks showing  
960 on Figure 9. The oldest eleven grains range between ca. 3825 and 3297 Ma. Except for one grain in the





961 Skillogalee Dolomite, these Eo- to Palaeoarchaeon grains are found in the Elatina Formation of the Marinoan  
962 glaciation, or in younger formations.

963 Locally, the Gawler Craton records magmatic events at ca. 3250 Ma, 3150 Ma, 2820 Ma, and 2560–2470  
964 Ma, and inherited/detrital zircon up to 3400 Ma (Fanning et al. 2007; Fraser et al. 2010; Fraser & Neumann  
965 2010; Jagodzinski & McAvaney 2017; McAvaney 2012; Reid & Jagodzinski 2011). Zircons of these ages may  
966 also be derived by recycling from the Willyama Supergroup in the Curnamona Province that contains detrital  
967 populations ca. 3000–2980 Ma, and ca. 2680–2650 Ma (Page et al. 2005). These may originally be sourced  
968 from the North Australian Craton (Barovich & Hand 2008). It is likely that zircon between ca. 3400 and ca.  
969 3290 Ma represent recycling of inherited zircon from the Gawler Craton. This still leaves six grains above ca.  
970 3400 Ma, with two being ca. 3800 Ma, which have no known local source.

971 The two ca. 3800 Ma grains are near concordant and have limited regions from which they can be sourced.  
972 Possible location that are relatively close (<5000 km) in contemporaneous reconstructions include recycling  
973 detrital zircon (up to ca. 4400 Ma) of the Narryer and Youanmi Terranes of the Yilgarn Craton, Western  
974 Australia (Wilde & Spaggiari 2007; Wyche 2007), the Anshan Region of the North China Craton, ca. 3811 to  
975 3800 Ma, (Liu et al. 2007), and the Mount Sones and Gage Ridge area of the Napier Complex, Antarctica, ca.  
976 3927 and 3850 Ma, (Black et al. 1986; Blewett et al. 2012; Harley & Kelly 2007) The concentration of  
977 zircons of this antiquity in the Ediacaran rocks may suggest a southern, Antarctic source, in keeping with the  
978 discussion below.

### 979 5.2.3. *Palaeoproterozoic*

980 The first population peak that is consistently recorded through the formations of the Adelaide Superbasin  
981 occurs at ca. 2480–2420 Ma [Figure 9]. This correlates well with the Sleaford Orogeny of the Gawler Craton  
982 (Reid et al. 2014). The most significant peak in the detrital spectra within the Palaeoproterozoic occurs ca.  
983 1700 Ma. This age maximum is part of a continuum from ca. 2000 Ma to the Mesoproterozoic. These  
984 Palaeoproterozoic grains are likely sourced from the surrounding Gawler Craton [Figure 5], which records  
985 numerous Palaeoproterozoic magmatic and metamorphic events (Belousova et al. 2009; Fanning et al.  
986 2007; Fraser & Neumann 2010; Jagodzinski & Fricke 2010; Jagodzinski & McAvaney 2017; McAvaney 2012;



987 Meaney 2012; 2017; Morrissey et al. 2019; Reid & Hand 2012; Reid & Jagodzinski 2011; Reid & Payne  
988 2017; Swain et al. 2005), and recycling from the Curnamona Province, where likely Arunta Orogen [Figure 5]  
989 derived detritus (ca. 1790–1770 Ma) is found in the sedimentary sequences (Barovich & Hand 2008). The  
990 Yavapai-Mazatzal Province of Laurentia [Figure 5] is a further possible source due to similarities in ages and  
991 proximity to the Adelaide Superbasin within some Rodinia reconstructions [Figure 2] (Brookfield 1993;  
992 Dalziel 1991; Goodge et al. 2008; Hoffman 1991; Karlstrom & Bowring 1988; Karlstrom et al. 1999; Moores  
993 1991; Wingate et al. 2002). The predominance of Palaeoproterozoic detrital zircon reduces significantly up  
994 stratigraphy, becoming negligible in the Ediacaran sedimentary rocks of the Adelaide Superbasin [Figure 9],  
995 indicating a shift in predominant detritus source.

#### 996 5.2.4. *Mesoproterozoic*

997 There is a major age peak ca. 1590–1550 Ma [Figure 9] that is present in Tonian formations of the Adelaide  
998 Superbasin that is not seen in the Ediacaran formations. The two most probable sources of these detrital  
999 zircon grains are the Ninnerie Supersuite and Radium Creek Group of the Curnamona Province (Armit et al.  
1000 2014; Wade, CE 2011), rocks of the Olarian Orogeny, the Isan Orogeny, and the Gawler Range Volcanics and  
1001 Hiltaba Suite of the Gawler Craton (Fanning et al. 2007). The near absence of this peak within the Ediacaran  
1002 formations of the Adelaide Superbasin [Figure 9] further suggests a change in predominant detrital sources  
1003 up stratigraphy.

1004 The second major peak in the Mesoproterozoic occurs ca. 1180–1050 Ma [Figure 9]. This late  
1005 Mesoproterozoic peak becomes predominant in the latest Tonian, then declines in prevalence in early  
1006 Cryogenian rocks, returning to significance in the middle Cryogenian and Ediacaran formations [Figure 9].  
1007 This return to prominence occurs between the two “Snowball Earth” events in the middle Cryogenian  
1008 (Hoffman et al. 2017; Hoffman et al. 1998; Hoffman & Li 2009), at the same time as the early  
1009 Mesoproterozoic peak decreases in significance [Figure 9]. Interestingly, this late Mesoproterozoic peak  
1010 shifts from ca. 1180–1150 Ma to ca. 1090 Ma at about this time, with the peak younging correlating with the  
1011 increased youth of the sequences [Figure 9]. These detrital zircons are likely sourced from the Pitjantjatjara  
1012 and Warakurna Supersuites of the Musgrave Province [Figure 5] (Smithies et al. 2008; Smithies et al. 2011;

1013 Smits et al. 2014; Wade, BP et al. 2008).  
1014 Other potential sources of Mesoproterozoic zircon include the Albany–Fraser Orogeny of Western Australia  
1015 (Spaggiari et al. 2015), which would require transport across the Gawler Craton [Figure 5]. Antarctic sources  
1016 are also possible, which is where the late Mesoproterozoic/early Tonian zircon in the Palaeozoic Lachlan  
1017 Orogen it thought to be derived (Squire et al. 2006). However, a distinguishing feature of these Lachlan  
1018 Orogen zircons is the significant amount of <1050 Ma zircon, these are more characteristic of parts of East  
1019 Antarctica such as the Tonian Oceanic Arc Super Terrane (TOAST, Jacobs et al. (2015)) and the Rayner  
1020 Complex (Fitzsimons 2000).

#### 1021 5.2.5. *Neoproterozoic*

1022 Neoproterozoic zircon populations are mostly absent in the older formations, which suggests limited to no  
1023 sourcing of syndepositional magmatic zircons. This agrees with primarily mafic magmatism at the initial  
1024 stages of the rift basin's development (Hillyard 1990; Preiss 1987). Cryogenian and younger formations  
1025 commonly preserve limited Neoproterozoic detrital zircons, with a few samples containing moderate  
1026 concentrations of 740–600 Ma detritus [Figure 8, Figure 9]. The first local sources of felsic magmatism occur  
1027 at ca. 800 Ma (Fanning et al. 1986) after which syndepositional age zircon begins to show in the age spectra.  
1028 The sources of these late Tonian to early Ediacaran zircons (ca. 800–590 Ma) are difficult to determine as  
1029 there are no known local sources for these late Tonian–early Ediacaran zircon. There is minor evidence for  
1030 volcanism at ca. 790–780 Ma (Preiss et al. 2009), ca. 663 Ma (Cox et al. 2018; Fanning & Link 2006) and  
1031 then ca. 580 Ma (Black 2007), but little evidence for voluminous local sources of the observed detrital  
1032 zircon. It has previously been posited that these detrital zircon may come from a source within Antarctica  
1033 [Figure 5] (Veevers et al. 2006) or in part the East African Orogen (Squire et al. 2006). More recent models  
1034 for formation of the East African Orogen preclude sources from this distance for pre-550 Ma formations as  
1035 the Mozambique Ocean did not close until this time (Merdith et al. 2017a; Merdith et al. (submitted); Schmitt  
1036 et al. 2018). More proximal Antarctic sources [Figure 5] from the Ross Orogen, or beneath the ice cover,  
1037 cannot be discounted.



1038 *5.3. Tectonic and Palaeogeographic Evolution*

1039 The Adelaide Superbasin formed via continental rifting with coincident fluvial, glacial, and marine  
1040 sedimentation. It formed in a series of restricted basins that evolved into marine conditions as Laurentia  
1041 moved away from Australia and the Pacific Ocean basin developed. The lithostratigraphic evolution of the  
1042 basin is described in detail in Preiss (1987) and Preiss (2000); however, there are still unknowns, such as  
1043 what was on the eastern margin of the Adelaide Superbasin [Figure 2]. Much of the detrital zircon research, a  
1044 key component of tectonic reconstruction, postdates these publications. Here we integrate detrital zircon  
1045 and other more recently published chronological constraints to set up a chronostratigraphic and sediment  
1046 pathway framework for the Adelaide Superbasin.

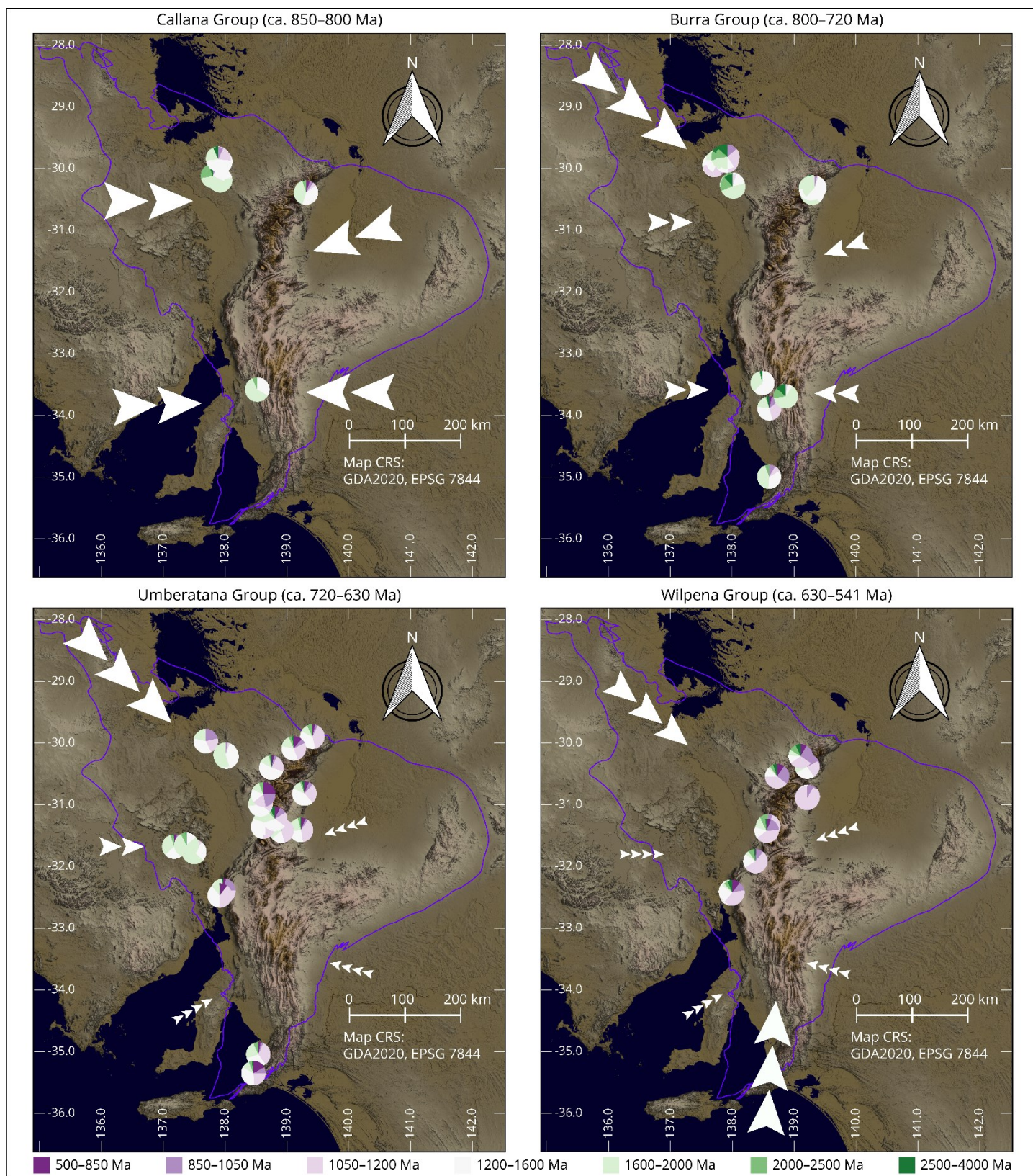
1047 Initial rifting appears to have developed over an extended period with detritus input initially supplied by local  
1048 sources from the rift shoulders [Figure 8, Figure 9 & Figure 10]. During the late Tonian there is a prominent  
1049 shift toward younger, late Mesoproterozoic zircon detritus [Figure 9]. This new source is inferred to be from  
1050 the Musgrave Province, with sediment distributed along the axis of the NW-SE Willouran rift [Figure 3], which  
1051 fed sediment south into the Adelaide Superbasin. The Sturtian Glaciation punctuates this detrital  
1052 progression with the earliest Cryogenian formations being dominated with early Mesoproterozoic zircon that  
1053 is interpreted to reflect a return to erosion from local rift-shoulders and more distributed sediment sourcing  
1054 [Figure 8, Figure 9].

1055 The middle Cryogenian sees a return to predominantly younger Mesoproterozoic populations, with the  
1056 addition of near depositional-age zircon populations and decreasing populations of early Mesoproterozoic  
1057 zircon [Figure 9]. Stratigraphically, this change occurs at the Tapley Hill Formation [Figure 9, Figure 10],  
1058 representing a transgression after the Sturtian glaciation (Preiss 2000). The subsequent Marinoan glacial  
1059 deposits demonstrate the importance of looking at contemporaneous formations deposited in different  
1060 regions to understand sediment distributary patterns. The Whyalla Sandstone is a broad time equivalent of  
1061 the Elatina Formation, both being deposits from the Marinoan glaciation. Yet, the two formations show quite  
1062 different zircon age spectra [Figure 8, Figure 9], indicating different source regions, or at least, different  
1063 sediment distribution pathways [Figure 11]. Rose et al. (2013), suggested that the ca. 1700 Ma peak in the



1064 Whyalla Sandstone spectra may have been ultimately derived from the Yavapai-Mazatzal Province of  
1065 Laurentia but was recycled from the underlying Mesoproterozoic Pandurra Formation. The focus of  
1066 Musgrave-derived detritus within the Elatina Formation; however, suggests that the detritus that filled up the  
1067 ARC depocentres were focussed along a well-developed and deepened rift by this late Cryogenian time, with  
1068 glacial and river systems flowing from the north-west through the Willouran Trough [Figure 3, Figure 11]  
1069 (Counts 2016; Wade, BP et al. 2005).





1070



1071 **Figure 11** –Generalised overview of provenance change through the Neoproterozoic for the Adelaide Rift Superbasin based on the  
1072 reconstruction in Figure 5. Sediment was mainly sourced locally (Gawler Craton, Curnamona Province, and possibly Laurentian  
1073 equivalents) from the rift shoulders during the early development of the basin in the middle Tonian ca. 850 Ma. Just prior to the Sturtian  
1074 Glaciation (ca. 720) there is a subtle change toward a younger Mesoproterozoic population [see Figure 9]. The Sturtian glacial deposits  
1075 represent a return to more locally derived sources; but, are followed by a rapid change toward the younger Mesoproterozoic population,  
1076 attributed to being derived from the Musgrave Province. Up stratigraphy in the Ediacaran there is a subtle shift in the young  
1077 Mesoproterozoic population that coincides with an increasing population of young zircon (<ca. 740 Ma) that we suggest may come  
1078 from southern (Antarctic) sources. Pie charts show counts of age groups within a sample. Arrows show generalised sediment pathways,  
1079 with their size indicating relative predominance.

1080 The early Mesoproterozoic zircons diminish to minor amounts in the Ediacaran formations of the Adelaide  
1081 Superbasin, whereas the late Mesoproterozoic population becomes dominant [Figure 9]. Early  
1082 Neoproterozoic and near syndepositional aged zircons also increase in prevalence both suggesting differing  
1083 detrital sources from the older formations of the Adelaide Superbasin, a detail reflected well in the MDS  
1084 plots [Figure 10].

1085 The source of the latest Tonian to Ediacaran zircon remains enigmatic. Interestingly, rare Eo- to  
1086 Palaeoarchaeon zircon, > ca. 3400 Ma, are more common in the Ediacaran formations [Figure 9]. To date, no  
1087 zircon of these ages has been found in local source terranes. There is also a slight shift in the peak of the late  
1088 Mesoproterozoic populations from ca. 1180 Ma to ca. 1090 Ma in the youngest Ediacaran Formations [Figure  
1089 8]. These observations suggest farther field detrital input, although the sources for these rare > ca. 3400 Ma,  
1090 and younger ca. 1050–1000 Ma zircons remains undetermined. More U–Pb detrital zircon data, in  
1091 combination with Lu–Hf and other rare earth and trace element data should help to identify this source. A  
1092 likely possibility is that this Ediacaran shift in source relates to the introduction of southerly-derived [Figure  
1093 11] sediment distribution systems that correlate to the beginning of orogenesis in the Antarctic Ross Orogen  
1094 (Cottle & Cooper 2006; Encarnación & Grunow 1996) which continues into the Palaeozoic and becomes the  
1095 dominant source for many of the sediments that make up the Terra Australis Orogen through eastern  
1096 Australia (Cawood 2005; Shaanan et al. 2018; Squire & Wilson 2005).

1097 Our findings largely support the big picture conclusions of previous provenance studies (Haines et al. 2004;  
1098 Keeman et al. 2020; Mackay 2011; Rose et al. 2013; Turner et al. 1993b) and palaeogeographic evolution  
1099 models (Powell et al. 1994; Preiss 1987; 2000; Turner et al. 1993b), including the development of rift  
1100 shoulders during the Cryogenian glaciations. However, the detail now presented illuminates the source-to-  
1101 sink evolution of the Adelaide Superbasin and provides a high-resolution temporal and tectono-geographic



1102 framework of the region in hitherto unprecedented detail. In particular, the integration of basin evolution and  
1103 focussing of northern-derived sediment distribution through the Tonian, followed by the effect of the Sturtian  
1104 glaciation on sediment sourcing directly followed by the beginning of southern sources is demonstrated here  
1105 in considerably more detail than previous studies have managed.

## 1106 **6. Conclusions**

1107 This paper presents the most comprehensive and only centralised database of both previously unpublished  
1108 and published detrital zircon geochronology for the Neoproterozoic of the Adelaide Superbasin, a key  
1109 Neoproterozoic basin. Although this data set is large it covers only 27 formations of the 143 formations in the  
1110 Neoproterozoic of the Adelaide Superbasin, many of which would be suitable for detrital zircon or whole rock  
1111 geochronology. Within the entire filtered dataset presented here, approximately 70% comes from six  
1112 formations and many of the formations have fewer than 100 filtered analyses. Because of this, provenance  
1113 tracing and source-to-sink analysis is necessarily rudimentary, but we see this developing rapidly from this  
1114 framework in future years with additional data and data from other provenance techniques, such as zircon  
1115 Lu–Hf, zircon rare earth element data and other mineral chemical data. Maximum depositional ages are  
1116 summarised and broad provenance constraints for the formations have been made whilst acknowledging the  
1117 limits of the current data.

1118 This research provides a comprehensive provenance study for the entire basin, with data used to interpret a  
1119 broad evolution of the rift system over time. Initial sediment was sourced locally from the rift shoulders (the  
1120 Gawler Craton and Curnamona Province). Later, development of the rift basin led to sediment being axially  
1121 sourced from far field sources that are inferred to be the Musgrave Province. The Sturtian glaciation saw a  
1122 short-lived increase in local derivation, presumably as topography was eroded by the widespread ice cover.  
1123 The Ediacaran shift in late Mesoproterozoic population zircon ages, introduction of Neoproterozoic zircons  
1124 and rare Eoarchaeon/Palaeoarchaeon populations are used to suggest a switch to Antarctic sources that  
1125 became dominant in the Palaeozoic.

1126 This study presents a framework for future work into the understanding of the age, provenance, and  
1127 sedimentary pathways for this vast basin. It identifies data gaps in the geochronological and provenance





1128 framework for the Neoproterozoic of the Adelaide Superbasin and forms the basis for continuing research  
1129 into the palaeo-tectonic geography of the Adelaide Superbasin. Further, this framework will provide  
1130 invaluable information for the continuing research of this key Neoproterozoic basin regarding the globally  
1131 momentous events it records, their timing and global correlations.

### 1132 **CRedit author statement**

1133 **Jarred C. Lloyd:** Conceptualisation, investigation, writing - original draft, writing - review & editing,  
1134 methodology, formal analysis, data curation, visualisation. **Morgan L. Blades:** Writing - original draft, writing  
1135 - review & editing, investigation, visualisation. **John W. Counts:** Writing - review & editing, conceptualisation,  
1136 investigation. **Alan S. Collins:** Conceptualisation, funding acquisition, supervision, writing - review & editing,  
1137 **Kathryn J. Amos:** Conceptualisation, supervision, writing - review & editing. **Benjamin P. Wade:**  
1138 Investigation, writing - review & editing. **James W. Hall:** Investigation **Stephen Hore:** Investigation.  
1139 **Ashleigh L. Ball:** Investigation. **Sameh Shahin:** Investigation. **Matthew Drabsch:** Investigation. **Alexander**  
1140 **Prohoroff:** Investigation.

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## 1159 **Data Availability**

1160 Data for this publication is hosted on Figshare, Lloyd et al. (2020),  
1161 <https://doi.org/10.6084/m9.figshare.11806179.v4>. This dataset contains all the U-Pb geochronology data  
1162 and basic sample details, including geographic coordinates, used in this study.

1163 Updated, detailed stratigraphic correlations for the Neoproterozoic sequences of the Adelaide Superbasin  
1164 can be found at <https://doi.org/10.6084/m9.figshare.11812047> (Lloyd 2020)

1165 Whilst these datasets will be maintained and updated with new data version all previous versions will remain  
1166 available.

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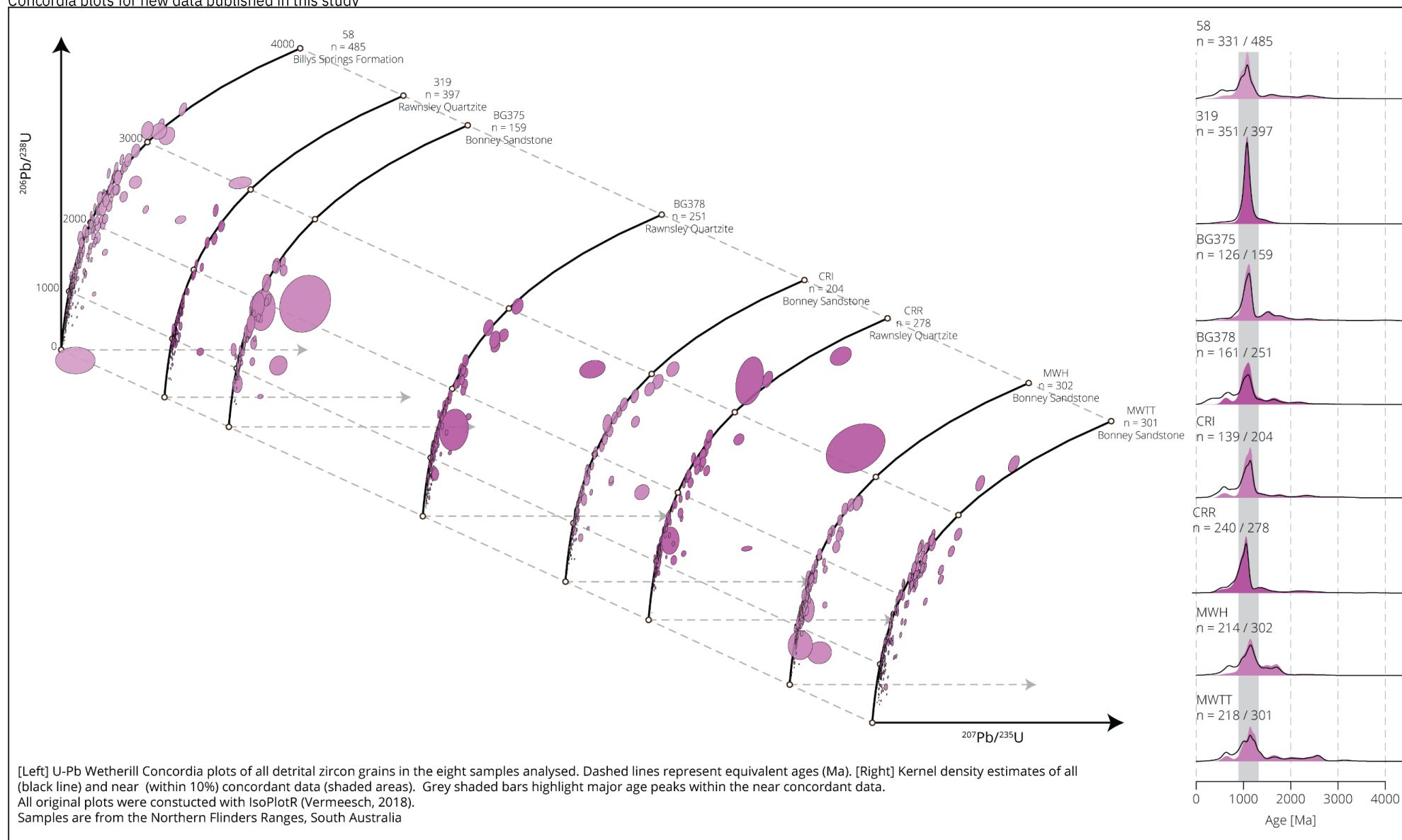
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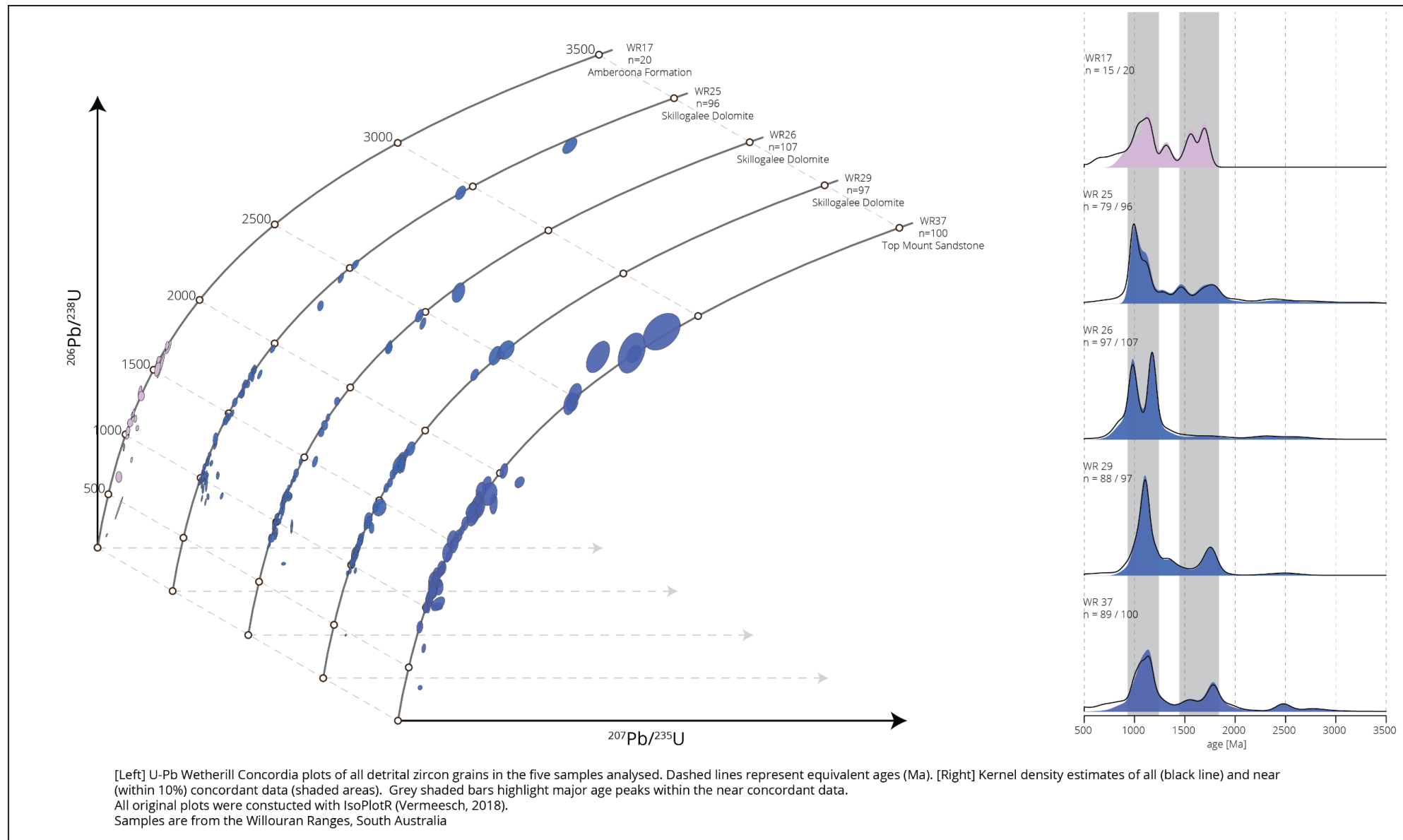
## Appendix One

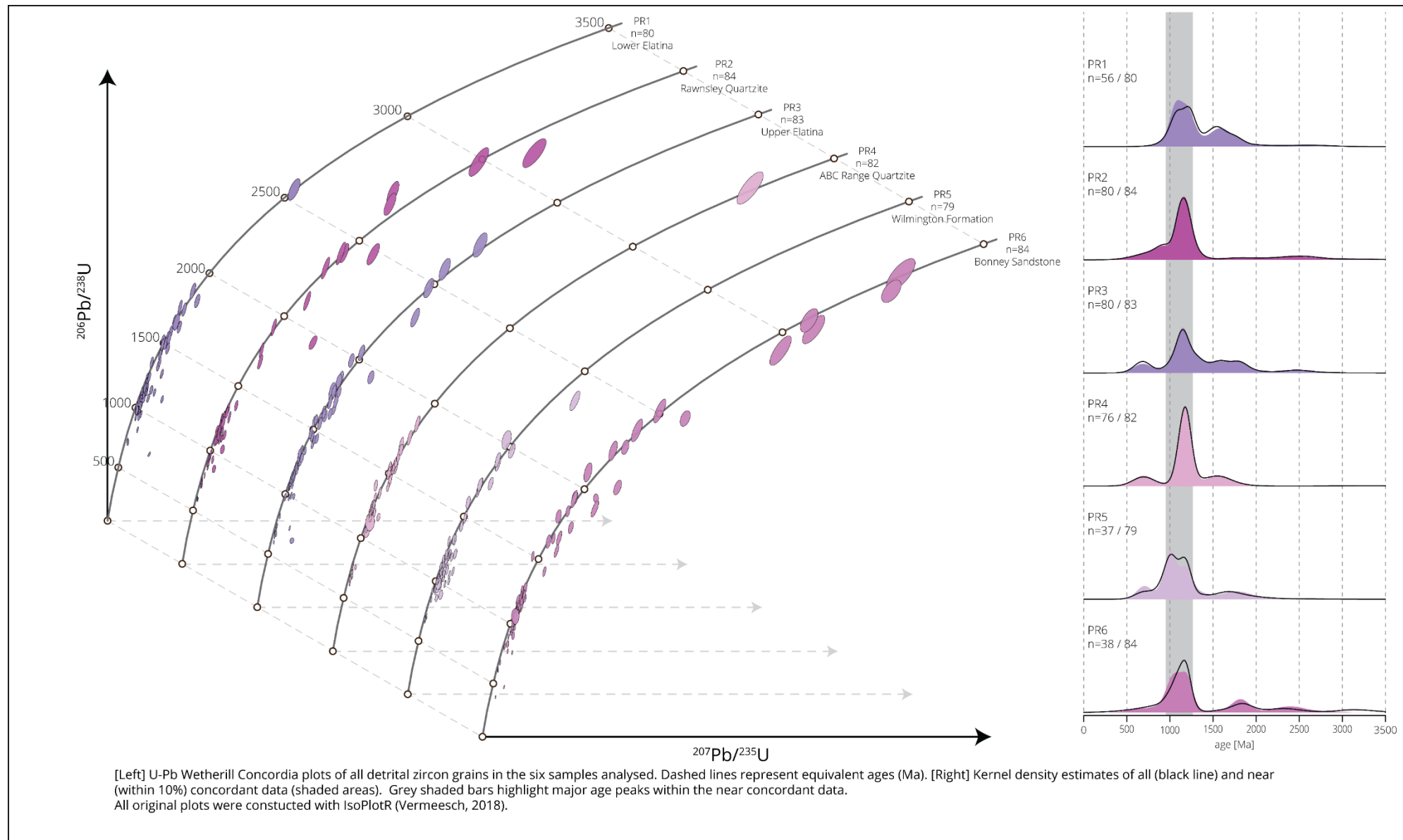


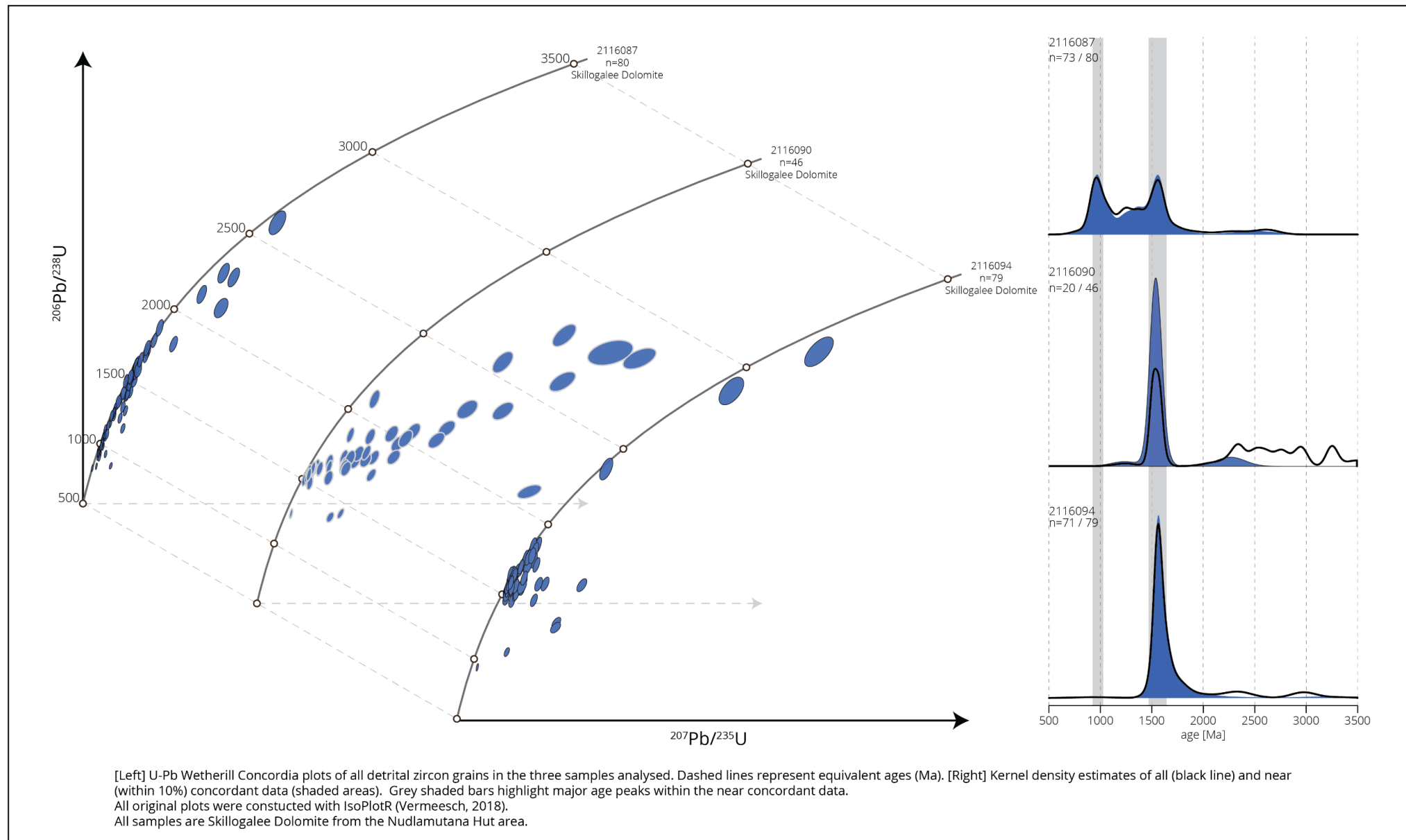


Concordia plots for new data published in this study









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