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**Article:**

Armit, RJ, Betts, PG, Schaefer, BF et al. (2014) Provenance of the Early Mesoproterozoic Radium Creek Group in the northern Mount Painter Inlier: Correlating isotopic signatures to inform tectonic reconstructions. *Precambrian Research*, 243. 63 - 87. ISSN: 0301-9268

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Elsevier Editorial System(tm) for Precambrian Research  
Manuscript Draft

Manuscript Number: PRECAM3819R1

Title: Provenance of the Early Mesoproterozoic Radium Creek Group in the Northern Mount Painter Inlier: Correlating isotopic signatures to inform tectonic reconstructions

Article Type: Research Paper

Keywords: Radium Creek Group; Mount Painter Inlier; U-Pb maximum depositional ages; Hf isotopes; isotopic fingerprinting; Palaeogeographical reconstructions

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Abstract: New in-situ zircon LA-ICPMS geochronologic and Hf-isotope data from the Radium Creek Group within the Mount Painter Inlier provide important temporal constraints on the Early Mesoproterozoic palaeogeography of eastern Proterozoic Australia. The entire Radium Creek Group was deposited in a single basin forming phase, and has a maximum depositional age of  $1595 \pm 3.7$  Ma. Detrital zircon from these metasedimentary rocks have U-Pb age populations at ca. 1595 Ma, 1660-1680 Ma, 1710-1780 Ma, ca. 1850 Ma and ca. 2500 Ma. These grains are characterised by isotopically diverse and evolved sources, and have crystallised within predominantly felsic igneous host-rocks. The relative age spectra and isotopic character has more similarity with the Gawler Craton than the Arunta Block, Curnamona Province or the Mount Isa Inlier. These observations suggest that the Mount Painter Province was adjacent to the Gawler Craton in the Early Mesoproterozoic. Our data supports a coherent South Australian Craton at ca. 1595 Ma and a contiguous continental mass that included the North and South Australian cratons. The Mount Painter Inlier occupied a complex plate tectonic setting in the overriding plate of two convergent margins.

Randall Parrish  
Editor  
Precambrian Research

Dear Randall,

We have revised the manuscript titled "Provenance of the Early Mesoproterozoic Radium Creek Group in the Northern Mount Painter Inlier: Correlating isotopic signatures to inform tectonic reconstructions" co-authored by Robin Armit, Peter Betts, Bruce Schaefer, Matthew Pankhurst and David Giles for consideration for publication in Precambrian Research.

We thank you for the review of this manuscript. We have improved the manuscript in accordance with your recommendations and in particular address more fully the key points of debate outlined in the introduction. We have also included regional maps and simplified the local geological interpretations in order to make this paper more appealing to the readers of Precambrian Research.

We have outlined clearly how we have dealt with each and every comment raised by reviewers or editor in a tabulated list of changes in the file named "Revision notes.docx". We have also included a marked up version of the revised manuscript showing all of the changes made.

We hope this manuscript can still be considered for publication in Precambrian Research.

Yours Sincerely,

Robin Armit

PhD Candidate

arc linkage Project # LP0882000 "Unearthing the marginal terranes of the South Australian Craton: Keystone of Proterozoic Australia."

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## Revisions

### General comments – editor

As you might imagine, papers like this often appear full of local names and regional geology, and many readers unfamiliar will be confused, as some of the reviewers are. You need to make things less complex and confusing so that your paper appeals to more readers.

*We have included more detailed regional geology figures (Fig. 1a-c) that provides the reader with a clearer sense of the spatial and temporal distributions of geological terranes discussed in this manuscript. We have also simplified the geological nomenclature where possible and assigned geological units to clearly defined domains. This should make the arguments easier to follow and more appealing to international readers. A greater focus on the larger scale implications has been included to make this study more relevant to an international audience.*

Can I just remind you that earlier in the manuscript you state the key problems are  
The key points of debate are;

58 1) the location and polarity of subduction systems,

59 2) the timing of major depositional and collisional events,

60 3) the interpretation of the spatial positions of the North Australian and South Australian

61 Cratons through time with respect to one another (as a result of 1 and 2).

But your conclusions don't really very effectively come back to these larger issues

*We have developed the discussion section (4.6) and the conclusion extensively to more effectively tackle these larger issues. We have also included 2 new figures by way of Fig. 2 and Fig. 13 that show a number of the current palaeogeographical reconstruction models for the early Mesoproterozoic eastern Australia and a new model incorporating the findings of this study.*

*These revisions include:*

*“The implication of this interpretation is that the North and South Australian cratons were contiguous at ca. 1595 Ma placing the Mount Painter Inlier at the nexus of two convergent margins characterised by subduction zones that dip towards the continent interior. Perturbations in the dynamics of these convergent margins resulted in rapid tectonic switches following deposition of the Radium Creek Group. Our data provides a critical constraint for palaeogeographic reconstruction for eastern Australia at the Palaeo- to Mesoproterozoic transition.”*

### Reviewer 1

Lines 32-33. The second sentence in the introduction does not really say anything informative. Why is this approach better? I think that the introduction could be much more powerful if it focused on the tectonic/paleogeographic problems rather than on methods that have been previously been proven to be useful for this purpose.

*Revision 1 – Removed second line.*

Revision 2 – removed ancient supercontinents as this method works for all reconstructions not just ancient ones.

Line 34. Remove "our." It is unclear what the group is you are referring to.

*Revision 3 – removed “our”*

Lines 39, 40. See above.

*Revision 4 – removed “our” twice*

*replaced with “the” and “on”, rephrased line 40 to remove majority. Now reads “understanding the Proterozoic record of Australia underpins the knowledge of how this continent has evolved, and informs on global tectonics through time”*

Line 40-41 - rephrase

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*Revision 5 – Rephrased with “Central to Proterozoic Australia reconstruction models is the link between the South Australian Craton and the Northern Australian Craton”*

Line 42. The word nexus here and throughout is not used correctly and should be changed. This line reads like there is a relationship between Paleoproterozoic and Mesoproterozoic. You want to say this is an important time interval for Australian evolution so state that more clearly. E.g. ....particularly at the boundary between Paleoproterozoic and Mesoproterozoic times.

*Revision 6 – replaced “nexus” and rephrased as “particularly at the boundary between the Palaeoproterozoic and Mesoproterozoic times.”*

Line 44. Remove: "it was positioned in a complex paleogeographic environment," and join with the next sentence.

*Revision 7 – removed this sentence and joined it to next sentence to read “Current geologic/tectonic understanding of the Palaeo-Mesoproterozoic of eastern Australia suggests it was situated adjacent to two convergent margins”*

Line 45: Please be more specific here - at what time (Palaeo-Mesoproterozoic is 1.5 Ga)? What do you mean by eastern Australia in these content? Betts and Giles (2006) show some convergence between SAC and NAC, for example. Etc.

*Revision 8 – reworded to define the period to 1700-1500 Ma and eastern Australia to include the North and south Australia cratons. Now reads as “The tectonic model of Betts and Giles (2006) for ca. 1700-1500 Ma Palaeo-Mesoproterozoic of eastern Australia incorporating both the North and South Australia cratons suggests it was situated adjacent to, and were affected by, two convergent margins (Betts and Giles, 2006), which had a plume-related continental hotspot track superimposed upon them (Betts et al., 2007; 2009).”*

Line 52: "intra-continental back-arc rift system" is nonsense. Either intra-continental, or back-arc.

*Revision 9 – removed back-arc system and reworded for clarity to “whereby eastern Proterozoic Australia evolved between ca. 1730 and 1640 Ma by a series of large intra-continental rift system along the margins of the South Australian and North Australian cratons”*

Line 53. ...was subsequently inverted between 1640 and 1600 Ma...

*Revision 10 – changed ca. 1640-1600 Ma to “between ca. 1640 and 1600 Ma”*

Line 57 - : instead of ;

*Revision 11 – change made*

Lines 80-83. This section sounds like a proposal not part of the introduction. Again change nexus - these are geological time terms not locations with relationships.

*Revision 12- reworded paragraph to be part of the introduction and removed nexus. Paragraph now reads as” In this communication we investigate the provenance and depositional environment of sediments deposited in the Early Mesoproterozoic within the Mount Painter Inlier as they may provide constraints on the palaeogeography of both the Mount Painter Province and eastern Proterozoic Australia.”*

Line 96. This sentence is awkward and needs revision.

*Revision 13 – Re-worded paragraph to read “A major crustal-scale south-east-dipping discontinuity between the Moolawatana Domain and the Curnamona Province has been interpreted from the deep seismic reflection and magnetotelluric survey (08GA-C1) by Korsch et al. (2010). This discontinuity has been interpreted as separating distinct basement blocks. The basement below the Moolawatana Domain on the north-western side of the discontinuity is termed the Warrakimbo Seismic Block by Korsch et al. (2010). This seismic block is characterised by markedly lower reflectivity than the Yarramba Seismic Province which is interpreted to be basement to the Curnamona Province south-east of the major discontinuity (Korsch et al., 2010).”*

Line 103. Use of the word comprised in this sentence and throughout the manuscript is incorrect. Replace with "is composed of."

*Revision 14 – Replaced comprised to “is composed of” throughout manuscript*

Line 111. Multi-phased? = polyphase metamorphism

*Revision 15 – changed to polyphase metamorphism*

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Line 175. Remove "in extensive detail." This term is qualitative -- one person's extensive detail might mean not enough to someone else (e.g. analysis of 1000 zircons per sample).

*Revision 16– removed “in extensive detail”*

Line 176. Change " , with the remainder from..." to: and one from...

*Revision 17– Change made*

Line 184-185. Omit the last sentence of the paragraph.

*Revision 18– Sentence omitted*

Line 186. "we studied", not "we included"

*Revision 19 – change made*

Line 189 (404). see comment on line 103.

*Revision 20 – Changes made*

Line 195. Revise to read: ...detritus at the apparent time of Radium.... You have not yet established this in the manuscript.

*Revision 21 – added “apparent” as this has not been established in the manuscript*

Lines 405-410 (and general comment about each of the samples). Resolution of these apparent age peaks is overly precise especially when quoted at 1 sigma error. These are the values calculated by the unmix routine (e.g.  $1674.6 \pm 2.8$  Ma), but are not that precise in reality. From one sample to another a peak shows up somewhere between 1660 and 1680 Ma, but not in the same place and with different errors. These are likely the same population. I suggest just mentioning approximately where the peaks in the age distributions occur. You might also consider not using the PDF function, but rather changing to using a kernel density plot (e.g., Vermeesh).

*Revision 22 – Removed the overly precise values and replaced them with the approximate position of the peaks e.g. ca. 1660-1680 Ma etc. and updated the probability plots text in Fig. 6 to be consistent.*

Line 592. 1591-155? Ma

*Revision 23– changed to read “1591-1552 Ma”*

Lines 608-610. Omit this paragraph.

*Revision 24 – Paragraph omitted helping to shorten this section.*

Lines 682-707. Some of these populations of U-Pb age and Hf-isotopic composition are pretty small (<4 grains) and may not be representative. This should be noted.

*Revision 25 – added a paragraph at the end of section 4.3 it reads “It is important to note the small sample populations of zircons ( $n < 4$ ) representing the ca. 1710-1760 Ma, ca. 1850 Ma, ca. 1904 Ma events, it is therefore possible that the Hf isotopic signatures of these populations may not be truly representative. “*

Line 810. Telescopes --- reduces??

*Revision 26 – Replaced telescopes with reduces*

Lines 859-876. How could the Mount Painter region have been at the edge of the Gawler Craton at 1587 Ma when you have stated that it was sutured to the Curnamona Province before 1595 Ma? In the next paragraph you suggest that extension switched rapidly to shortening and then extension again. This suggests an intracratonic setting not a passive/active margin.

Part of this inconsistency relates to what appears to be a variable definition of the Gawler Craton and South Australia Craton throughout the manuscript. I suggest defining the geological provinces up front and then reconsidering inconsistent parts of this section.

*Revision 27 – Removed the statement “ the Mount Painter Province represents the eastern most marginal terrane of the Gawler Craton prior to ca. 1587 Ma. region have been at the edge of the Gawler Craton at 1587 Ma” and instead suggest that the Gawler Craton and Curnamona Province are likely co-located ca. 1595 Ma.*

*We still support convergent margin driven rapid tectonic settings and have developed this argument with “Repeated rapid switching from extension to shortening at convergent plate margins is common during transient episodes of flat subduction (Gutscher et al., 2002) or when subduction roll-back is interrupted by accretion of buoyant material such as an ocean plateau (Rosenbaum et al., 2005;*

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Mason et al., 2010), plume-head (Murphy et al., 1998; Betts et al., 2009; 2012), arc terrane (Boutelier et al., 2003) or continental micro-continent (Moresi et al., in review), which are all characterised by local trench advance and shortening in the overriding plate. We propose that during the ca. 1595-1555 Ma interval, the Mount Painter Inlier was located in the overriding plate of one or more subduction zones and was subjected to tectonic mode switches caused by disruption of a convergent margin.”

We have also defined the South, North and West Australian cratons in the introduction to remove the inconsistency related to the definition of the Gawler Craton versus South Australian Craton and followed this throughout the manuscript. “Proterozoic Australia can be considered following the geography-based nomenclature of Myer et al. (1996) in which the continent is divided into three major cratonic units, called the North, West and South Australian cratons (Fig. 1a). The South Australian Craton comprises the Gawler Craton and the Curnamona Province (Fig.1b-c).”

### **Reviewer 2 – Major comments**

It becomes especially difficult when the authors discuss the Hf-isotope correlations between various geological formations and then make conclusions about correlation of various terranes without citing which formation belongs to a specific terrane

*Revision 28 – Added more detailed regional map (Fig. 1a-c) which defines the geological domains and the geological formations that belong to each of these. Separation of the Hf isotope correlation figures into Fig 8, 11, 12 provides more clarity regarding which units and domains of the Gawler Craton are compared in the text. The text has been updated to match the domain names outlined in Fig. 1c and Fig. 11a and will provide for an easier assessment of the interpretations by the reader.*

1. Section 4.3 should be shortened and re-written with references to Figure 7. In present state it is very difficult to follow, especially for non-Australians. The same (but to a less extent) is applicable to the section 4.5.

*Revision 29 - Section 4.3 has been shortened where possible and re-written with reference to Figures 8, 11, 12 and the regional geological map in Fig. 1c. Section 4.5 has been split into a section “4.5 Comparison with regional datasets” and “4.6 Proterozoic tectonic implications”. Section 4.5 has also be re-written with reference to Figure 8, 11 and 12 as well as the regional geology map (Fig. 1c)*

2. Figure 7 itself needs revision and more comprehensive figure captions. For example, Fig. 7e contains only a combined plot for the units of the Gawler Craton, so it is difficult to follow discussions about correlation between Radium Creek Group with some specific units in Gawler. Some suggestions are in the annotated text.

*Revision 30 – The figure has been revised and separated into 3 different figures. Figure 8 contains the in-situ Hf plots for the Radium Creek Group in the Mount Painter Inlier Fig. 8a-b,d and the direct comparison with the samples of the Gawler Range Volcanics (uGRV) sample from the Gawler Craton, and the Frome Granite and Benagerie Volcanic Suite from the Curnamona Province in Fi. 8c). Figure 11 contains the larger datasets from the Gawler Craton. Fig 11a has the individual points for each geological domain and each author shown and compares these to the sampled from the Mount Painter Inlier. Fig. 11b shows the gridded field for all of the Gawler Craton in comparison to the point values for the Mount Painter samples. This will make is easier for a reader to follow the discussions regarding correlation between specific units in the Gawler Craton and the Mount Painter metasediments. Fig. 12 shows the Hf density field plots from the Arunta, Curnamona and Mt Isa terranes only. Breaking these figures into three separate figures makes each of the graphs easier to read. The text in section 4.3 and 4.5 has been re-written to reference these new figures.*

3. The last part of discussion about paleogeographic reconstructions should be illustrated at least with sketches of these reconstructions.

*Revision 31 – Illustrations of the most pertinent current reconstructions are added as Fig. 2a,b and discussed more fully in the introduction. A new figure (Fig. 13) has been added to develop on these existing models with the interpretations made in this paper. This section of the discussion has been*

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expanded to deal more effectively with the large scale issues introduced at the beginning of the manuscript.

### **Reviewer 2 – revisions in annotated text (pdf)**

Line 34 Remove “our”

*Revision 32 – change made*

Line 35 I would remove the end of the sentence "of ancient supercontinents". This method works for all reconstructions, not only reconstructions of supercontinents.

*Revision 33 - RA - Removed "ancient supercontinents"*

*RA - removed second line allowing for more focus on tectonic/palaeogeographic problems*

Line 40 "majority" is a wrong word here. Rephrase.

*Revision 34 - RA - rephrased and removed majority.*

*RA - Sentence now reads as "understanding the Proterozoic record of Australia underpins the knowledge of how this continent has evolved, and informs on global tectonics through time"*

Line 42 "...particularly between the..." sounds better.

*Revision 35 - RA - rephrased with "particularly at the boundary between the Palaeoproterozoic and Mesoproterozoic times."*

Line 43 This sentence is meaningless, better remove it.

*Revision 36 - RA - removed this sentence and joined with next sentence to read "Current geologic/tectonic understanding of the Palaeo-Mesoproterozoic of eastern Australia suggests it was situated adjacent to two convergent margins"*

Line 45 Please be more specific here - at what time (Palaeo-Mesoproterozoic is 1.5 Ga)? What do you mean by eastern Australia in these content? Betts and Giles (2006) show some convergence between SAC and NAC, for example. Etc.

*Revision 37 RA - reworded to define the period to 1700-1500 Ma and eastern Australia to include the North and south Australia cratons.*

*Now paragraph worded as "The tectonic model of Betts and Giles (2006) for ca. 1700-1500 Ma Palaeo-Mesoproterozoic of eastern Australia incorporating both the North and South Australia cratons suggests it was situated adjacent to, and were affected by, two convergent margins (Betts and Giles, 2006), which had a plume-related continental hotspot track superimposed upon them (Betts et al., 2007; 2009)."*

Line 52 "intra-continental back-arc rift system" is nonsense. Either intra-continental, or back-arc.

*Revision 38 RA - removed back arc system for clarity and reworded as "whereby eastern Proterozoic Australia evolved between ca. 1730 and 1640 Ma by a series of large intra-continental rift system along the margins of the South Australian and North Australian cratons"*

Line 53 missing “between”

*Revision 39 - RA- changed ca. 1640-1600 Ma to " between ca. 1640 and 1600 Ma"*

Line 57 : instead of ;

*Revision 40 – RA changed ; to :*

Line 92: Add Flinders Ranges in South Australia and Moolawatana Domain in Fig. 1c

*Revision 41- RA - added new figure as sub section of figure 1c with Flinders ranges and Moolawatana Domain shown*

Line 93 show in map

*Revision 42 RA - RA - added new figure as sub section of figure 1c with Flinders ranges and Moolawatana Domain shown*

Line 105 XXXX-YYYY for Late Palaeoproterozoic dates

*Revision 43 – removed “Late Palaeoproterozoic and section reads now as “These rocks have yielded Early Mesoproterozoic (1600-1580 Ma) maximum depositional U-Pb zircon ages*

Line 107 If they are significantly younger than 1640 Ma, they cannot be Palaeoproterozoic...

*Revision 44 - RA - Changed to read as ' Early Mesoproterozoic max depositional....'*

Line 117 Delete “either”

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*Revision 45 – RA - Paragraph removed as it is overly detailed for this communication*

Line 122 This paragraph should be more explicit. It is hard to understand, especially without illustrations.

*Revision 46 – RA -this paragraph has been removed as it is overly detailed for this communication*

Line 125 Add this age range to the legend in Figure 2.

*Revision 47 – RA- added to figure 2*

Line 127 "Mount Neill" occurs two times in the same sentence.

*Revision 48 – RA - rewritten this sentence as “The Mount Neill Suite was emplaced at ca. 1585-1557 Ma along the south-east margin of the inlier (Fig. 3). This suite incorporates the Box Bore and Mount Neill Granite (Elburg et al., 2012; Elburg et al., 2001; Fraser and Neumann, 2010). The slightly younger Moolawatana Suite was emplaced between ca. 1560 Ma and 1555 Ma (Stewart and Foden, 2001) on the northern side of the Inlier (Fig. 3).*

Line 128 Add this age range to the legend in Figure 2.

*Revision 49 – RA- added to figure 2*

Line 129 Add this age range to the legend in Figure 2.

*Revision 50 – RA- added to figure 2*

Line 186 "we studied", not "we included"

*Revision 51 – RA- change made*

Line 189 – composed instead of comprised

*Revision 52 – RA- change made*

Line 195. Revise to read “detritus at the apparent time of Radium.... You have not yet established this in the manuscript.

*Revision 53 - RA – added “apparent” as this has not been established in the manuscript*

Line 197. ..are taken from... and kilometre with small K

*Revision 54 - RA – change made and now reads “two samples are taken from drillholes ~150 kilometres to...”*

Line 204. Tectonic unit instead of tectonic element... add “the” to make “which is the key”

*Revision 55 - RA– Sentence re-worded as “They therefore contain information regarding the Early Mesoproterozoic evolution of Curnamona Province, which is a key to understanding the Mount Painter Inlier..”*

Line 346. 30-100 um should be 30 to 100um

*Revision 56 – RA – Change made*

Line 592 ?

*Revision 57 – RA – added a 2 to make the age range “1591-1552 Ma”*

Line 593 General comment to the whole section 4.3 References to parts of Figure 7 (a, b,c etc.) are needed, otherwise it is difficult to follow.

*Revision 58 - RA - To make this section easier to follow we have separated this figure into 3 (Figs 8, 11 and 12. Each of which have been cross referenced back to the text.*

Line 626 "not dissimilar" means "similar"? It is hard to assess, as in Fig. 7c the combination of Gawler Range Volcanics, Frome Granite and Benagerie Volcanics is shown (see line 735).

*Revision 59 – RA – changed “not dissimilar” to “are similar”.*

*Separated this figure into 3 different figures, figs 8, 11, 12. This has increased the size of the figure (Fig. 8c) that includes the GRV, Frome granite and BVS making it easier to assess. Point size for each dataset has also been increased to show the comparison between these units more clearly.*

Line 632 Shown in Fig. 7? Where?

*Revision 60 – RA - added reference to Fig. 8c*

Line 641 Shown in Fig. 7?

*Revision 61 – RA - added reference to Fig. 8c*

Line 646 Where is this mismatch demonstrated in Fig. 7?

*Revision 62 – RA - added reference to Fig. 8c and re-written sentence to “This group is appreciably*

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*more juvenile than the values for the upper Gawler Range Volcanics and Frome Granite (Fig. 8c). It is important to note that unlike the Radium Creek Group, we did not detect a more evolved and negative Hf component (-6 to -2) in this sample of Benagerie Volcanic Suite (Fig. 8c)."*

Line 763 - This is not obvious in the Fig. 7e at its present state.

Revision 63 – RA - added Fig. 11a-b to clarify this. This figure includes all of the U-Pb-Hf values for each of the terranes of the Gawler Craton as defined in Fig. 1c. and also separates these values based on the author the work is from.

Line 781. Why not shown in Fig. 7?

Revision 64 - RA – Now shown in Fig. 12b and referenced to this figure in the text.

Line 827 similar?

Revision 65 - RA – replaced 'not dissimilar' with 'similar'

Line 839 crust includes

Revision 66 - RA - added space between 'crust' and 'includes'

Line 879: Figures would help a lot for this discussion of the reconstruction models

Revision 67 – RA - Figure added to show the proposed reconstruction space at this time (Fig. 13) as well as other models including the Betts and Giles 2006 model and the Wade et al. 2006 model (Fig. 2)

Line 881 Illustrations would help a lot.

Revision 68 – RA - This model is presented in a new Fig. 2. It is also adapted into the the proposed model in Fig. 13

Line 924 Choose another fonts - the text in the map is barely visible.

Revision 69 – RA - font changed to make labels more legible.

Line 927 Already shown

Revision 70 – RA - omitted 2nd reference to the gps location

Line 991 7a? 7b? etc. - please add

Revision 71 - RA - added these labels. Now as Fig. 8a,b,c and Fig 11a,b and Fig 12a,b,c.

Line 1022 Tables 1 and two seem to be switched in this PDF

Revision 72 – RA - These have been swapped to read correctly with the text

Table numbers missing?

Revision 73 – RA – added table number to table and checked in upload

#### **Other changes made**

RA - changed the last sentence of the abstract.

Now reads as "These observations suggest that the Mount Painter Province was adjacent to the Gawler Craton in the Early Mesoproterozoic. Our data supports a coherent South Australian Craton at ca. 1595 Ma and a contiguous continental mass that included the North and South

Australian cratons. The Mount Painter Inlier occupied a complex plate tectonic setting in the overriding plate of two convergent margins."

Line 30 RA - moved this paragraph into section 1.4 Approach of this study.

Line 80 - RA - Paragraph re-written so that it is part of the introduction and less like a proposal. Now reads as "In this communication we investigate the provenance and depositional environment of sediments deposited in the Early Mesoproterozoic within the Mount Painter Inlier as they may provide constraints on the palaeogeography of both the Mount Painter Province and eastern Proterozoic Australia."

Line 96 RA - reworded paragraph and reads as "A major crustal-scale south-east-dipping discontinuity between the Moolawatana Domain and the Curnamona Province has been interpreted from the deep seismic reflection and magnetotelluric survey (08GA-C1) by Korsch et al. (2010). This discontinuity has been interpreted as separating distinct basement blocks. The basement below the Moolawatana Domain on the north-western side of the discontinuity is termed the Warrakimbo Seismic Block by Korsch et al. (2010). This seismic block is characterised by markedly lower reflectivity than the Yarramba Seismic Province which is interpreted to be basement to the Curnamona Province

*south-east of the major discontinuity (Korsch et al., 2010)."*

*Line 184 – RA – Sentence omitted*

*Line 335 – RA - changed to correct reference (Griffin et al. 2000)*

*Line 336 - RA - Changed to correct reference (Nowell et al. 1998)*

*Line 404 - RA - removed isoplot unmix routine age and mentioned approx. peaks at ca. 1680 Ma and 1730 Ma*

*Line 407 – RA –sentence omitted as overly interpreted*

*Line 608 – RA - Paragraph omitted helping to shorten this section.*

*Line 679-681 - RA - removed sentence "In all of the Radium Creek Group..."*

*To shorten this section and is a unneeded detail.*

*Line 685 RA - removed paragraph. This does not add to the manuscript and has been removed to shorten the section*

*Line 699-702 - RA - removed the sentence "A slightly older ca. 1904 Ma U..... This observations is overly interpreted and not crucial to the aims of the paper.*

*Line 729 – RA - This section has been renamed as "4.5 Comparison with regional datasets" and discusses and compares the U/Pb and Hf regional datasets across eastern Proterozoic Australia. The discussion on tectonic implications is now in section 4.6*

*Line 745 – RA - removed the end of this sentence " which was accompanied by localised dep... Overly detailed for the outcomes of the communication*

*Line 805-809 – RA - removed the first 2 sentences*

*This shortens the section as these interpretations are too detailed for the scope of the paper.*

*Line 852 – RA - split this section at line 852.*

*Korsch et al..... is incorporated into the new section 4.6 Proterozoic tectonic implication.*

*This section has also been expanded to more properly assess the large scale implications of the study.*

*Line 868 – RA - The paragraph has been re-written to remove the marginal terrane aspect and now reads as "Further, the isotopic and geochemical similarities between the Upper Gawler Range Volcanics and the Benagerie Volcanic Suite (Wade et al., 2012) suggests the lower crust in the footwall of the palaeo-Paralana Fault may represent the same crustal sources (e.g. Pankhurst et al., 2013) of magmatism as the central Gawler Craton. The correlation of the upper Gawler Range Volcanics with the Benagerie Volcanic Suite in the Curnamona Province (Wade et al., 2012) stitches the Gawler Craton and Curnamona Province together at ca. 1587 Ma."*

*Line 874 – RA - This section has been re-written to develop more expansively on the large scale implications and palaeogeographical reconstructions.*

*Line 885 – RA – Conclusion re-written to more fully develop the large scale reconstruction implications*

*Figure 1 – RA - updated figure to include 1a,1b and 1c. These layout the NAC, SAC and WAC positions in Proterozoic Australian palaeogeography (Fig. 1a) and provide detail on the geological terranes of both the Curnamona Province and Gawler Craton (Fig. 1c)*

*Figure 2 – RA - New Figure 2 added here. This figure outlines the Betts and Giles (2006) and Wade et al. 2006 reconstruction space in the early Mesoproterozoic.*

*Figure 3 – RA – Now as Figure 3. Date ranges added for intrusive suites. Text on image changed to arial to be clearer.*

*Figure 7 – RA- this figure has been moved into three different figures (fig 8, 11 and 12) and includes more detail for the Gawler terranes as well as bigger and more readable figure for the comparison of the RCG with the Gawler Range Volcanics etc. (Fig 8c)*

*Figure 11-13 – RA - Figures 11-13 added here.*

*These include Fig 11- in situ zircons Hf isotopes of the Gawler Craton plot; Fig 12 - in situ zircons Hf isotopes of the Arunta Block, Curnamona Province and Mount Isa Inlier; Fig 13 - palaeogeographical reconstruction for the Mount Painter Inlier ca. 1595-1555 Ma.*



Research Highlights

- The Radium Creek Group has a maximum depositional age of  $1595 \pm 3.7$ Ma.
- Zircons from the RCG have an isotopically diverse Hf isotopic fingerprint.
- The Radium Creek Group is interpreted to be derived from the Gawler Craton.
- The Curnamona Province and Gawler Craton were co-located at ca. 1595 Ma.
- The Mount Painter Inlier developed at the nexus of two convergent margins.

1 **Provenance of the Early Mesoproterozoic Radium Creek Group in the**  
2 **Northern Mount Painter Inlier: Correlating isotopic signatures to**  
3 **inform tectonic reconstructions.**

4

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11

12 New in-situ zircon LA-ICPMS geochronologic and Hf-isotope data from the  
13 Radium Creek Group within the Mount Painter Inlier provide important  
14 temporal constraints on the Early Mesoproterozoic palaeogeography of  
15 eastern Proterozoic Australia. The entire Radium Creek Group was deposited  
16 in a single basin forming phase, and has a maximum depositional age of  
17  $1595 \pm 3.7$  Ma. Detrital zircon from these metasedimentary rocks have U-Pb  
18 age populations at ca. 1595 Ma, 1660-1680 Ma, 1710-1780 Ma, ca. 1850 Ma  
19 and ca. 2500 Ma. These grains are characterised by isotopically diverse and  
20 evolved sources, and have crystallised within predominantly felsic igneous  
21 host-rocks. The relative age spectra and isotopic character has more  
22 similarity with the Gawler Craton than the Arunta Block, Curnamona Province  
23 or the Mount Isa Inlier. These observations suggest that the Mount Painter  
24 Province was adjacent to the Gawler Craton in the Early Mesoproterozoic.  
25 Our data supports a coherent South Australian Craton at ca. 1595 Ma and a  
26 contiguous continental mass that included the North and South Australian  
27 cratons. The Mount Painter Inlier occupied a complex plate tectonic setting  
28 in the overriding plate of two convergent margins.

29 *Keywords: Radium Creek Group, Mount Painter Inlier, U-Pb maximum depositional ages, Hf isotopes,*  
30 *isotopic fingerprinting, Palaeogeographical reconstructions*

31 **1. Introduction**

32 Tectonic reconstruction models of Proterozoic Australia have been enthusiastically debated in the  
33 literature (c.f. Betts and Giles, 2006; Gibson et al., 2008; Giles et al., 2004; Korsch et al., 2009; Swain  
34 et al., 2008; Wade et al., 2006). This is because understanding the Proterozoic record of Australia  
35 underpins the knowledge of how this continent has evolved, which informs the view of global  
36 tectonics through time.

37 Proterozoic Australia can be considered following the geography-based nomenclature of Myer et al.  
38 (1996) in which the continent is divided into three major cratonic units, called the North, West and  
39 South Australian cratons (Fig. 1a). The South Australian Craton comprises the Gawler Craton and the  
40 Curnamona Province (Fig.1b-c). The South Australian Craton has a shared history with the North  
41 Australian Craton between ca. 1800 and 1550 Ma, suggesting that were contiguous during this  
42 interval. The South Australian Craton likely separated from the North Australian Craton during the  
43 Mesoproterozoic to form a discrete cratonic element (Giles et al., 2004). Consequently, the link  
44 between the South Australian Craton and the Northern Australian Craton, particularly at the  
45 boundary between the Palaeoproterozoic and Mesoproterozoic times is significant for determining  
46 the evolution of the Australian continent at this time.

47 Giles et al. (2004) interpreted a configuration of the Palaeoproterozoic Australia where the South  
48 Australian Craton was rotated  $52^{\circ}$  counter clockwise around an Euler pole in the North Australian  
49 Craton. This configuration aligned contemporaneous orogenic belts across the Gawler Craton,  
50 Arunta Inlier, Mount Isa Inlier and the Curnamona Province (Fig. 2a). Using the configuration of Giles  
51 et al. (2004), Betts and Giles (2006) suggested that between ca. 1700 and 1500 Ma, the contiguous  
52 North and South Australia cratons (Fig 2a) were situated adjacent to, and were affected by, two  
53 convergent margins. A plume-related continental hotspot track was also superimposed upon these  
54 cratons (Betts et al., 2007; 2009). In this model, the southern margin of the Australian continent  
55 evolved in the overriding plate of a north-dipping subduction, and the eastern margin of the  
56 continent sequentially evolved from a passive margin, to a convergent margin with west-dipping  
57 subduction.

58 Wade et al. (2006) presented an alternative model in which the South Australian Craton collided  
59 with the North Australian Craton between ca. 1590 Ma and 1560 Ma (Fig. 2b), chiefly supported by  
60 the identification of the ca. 1590 Ma continental-arc affinity rocks in the Musgrave Block of central  
61 Australia. In this model the continental arc rocks formed above a south-dipping subduction zone  
62 and the Gawler Craton evolved in a continental back-arc basin. Gibson et al. (2008) proposed a  
63 model whereby eastern Proterozoic Australia evolved between ca. 1730 and 1640 Ma by a series of  
64 large intra-continental rift systems along the margins of the South Australian and North Australian  
65 cratons. This system was subsequently inverted between ca. 1640 and 1600 Ma during accretion of  
66 the Georgetown-Mojave Block. These latter models consider the present-day distribution of  
67 Australia Palaeoproterozoic terranes to be representative of their distribution at the time of  
68 tectonism.

69 The key points of debate are:

- 70 1) the location and polarity of subduction systems,
- 71 2) the timing of major depositional and collisional events,
- 72 3) the interpretation of the spatial positions of the North Australian and South Australian
- 73 Cratons through time with respect to one another (as a result of 1 and 2).

74 Increasing our knowledge of these tectonic settings will improve our understanding of the Palaeo-  
75 Mesoproterozoic evolution of Australia. Moreover, the knowledge will provide important constraints  
76 to larger-scale Nuna-Columbia supercontinent reconstructions.

## 77 **1.2 A key terrane**

78 The Mount Painter Inlier is situated within the northern, South Australian Craton margin (Fig. 1b-c),  
79 which makes it an ideal location to explore the links between the North and South Australian  
80 cratons. In addition, this inlier helps us investigate the interface between the Gawler Craton and  
81 northern Curnamona Province, which is currently poorly understood.

82 Recently, Armit et al. (2012) suggested that the Early Mesoproterozoic deformation events recorded  
83 in the Mount Painter Inlier appear to be more similar to those observed in the northern Gawler  
84 Craton and Mount Isa Inlier, rather than the southern Gawler Craton and Curnamona Province.  
85 According to that study, the Mount Painter region would be predicted to record an evolution more  
86 similar to that of the North Australian Craton rather than the South Australian Craton. If this is  
87 indeed the case, our interpretations of the relationships between these crustal elements and the  
88 reconstructions to place the Mount Painter Inlier in its correct location through time, require a  
89 substantial re-appraisal.

90 We investigate the provenance and depositional environment of sedimentary rocks deposited in the  
91 Early Mesoproterozoic within the Mount Painter Inlier as they may provide constraints on the  
92 palaeogeography of both the Mount Painter Province and eastern Proterozoic Australia.

## 93 **1.3 Geological Background**

### 94 **1.3.1 Crustal architecture**

95 The Radium Creek Group (Preiss et al., 2010; a nomenclature revised from the Radium Creek  
96 Metamorphics) outcrops within the Mount Painter and Mount Babbage inliers, which are located at  
97 the northern tip of the Flinders Ranges in South Australia (see Fig. 1c). These Inliers have been  
98 interpreted as part of the Moolawatana Domain (Fig. 1c) that defines the north-western extent of  
99 the Curnamona Province (Conor and Preiss, 2008; Parker et al., 1993; Teale and Flint, 1993).

100 A major crustal-scale south-east-dipping discontinuity between the Moolawatana Domain and the  
101 Curnamona Province has been interpreted from the deep seismic reflection and magnetotelluric

102 survey (08GA-C1) by Korsch et al. (2010). This discontinuity has been interpreted as separating  
103 distinct basement blocks. The basement below the Moolawatana Domain on the north-western side  
104 of the discontinuity is termed the Warrakimbo Seismic Block by Korsch et al. (2010). This seismic  
105 block is characterised by markedly lower reflectivity than the Yarramba Seismic Province which is  
106 interpreted to be basement to the Curnamona Province south-east of the major discontinuity  
107 (Korsch et al., 2010).

### 108 1.3.2 Stratigraphy

109 Within the northern Mount Painter Inlier, the Radium Creek Group is composed of micaceous  
110 psammites, psammopelites, pelitic schists, phyllites, feldspathic quartzites and quartzofeldspathic  
111 gneisses (Fig. 3). These rocks have yielded Early Mesoproterozoic (1600-1580 Ma) maximum  
112 depositional U-Pb zircon ages (Elburg et al., 2012; Fanning et al., 2003; Fraser and Neumann, 2010).  
113 These ages appear to be significantly younger than the ca. 1720-1640 Ma Willyama Supergroup ca.  
114 1720-1640 Ma (Conor and Preiss, 2008) from the southern part of the Curnamona Province and  
115 therefore previous correlations with the Radium Creek Group are considered erroneous (e.g. Teale,  
116 1993). The Radium Creek Group has undergone polyphase metamorphism (Elburg et al., 2003;  
117 McLaren et al., 2002) and poly-deformation in the Early Mesoproterozoic and Palaeozoic (Armit et  
118 al., 2012).

### 119 1.3.3 Igneous suites

120 The metasedimentary rocks of the Mount Painter Province are intruded by a series of Early  
121 Mesoproterozoic igneous suites with A-type geochemical affinities (Elburg et al., 2012; Kromkhun et  
122 al., 2013). The Mount Neill Suite was emplaced at ca. 1585-1557 Ma along the south-east margin of  
123 the inlier (Fig. 3). This suite incorporates the Box Bore and Mount Neill Granite (Elburg et al., 2012;  
124 Elburg et al., 2001; Fraser and Neumann, 2010). The slightly younger Moolawatana Suite was  
125 emplaced between ca. 1560 Ma and 1555 Ma (Stewart and Foden, 2001) on the northern side of the  
126 Inlier (Fig. 3). The ca. 1552 Ma Hodgkinson Granodiorite (Fraser and Neumann, 2010) also intrudes  
127 the central part of the Inlier and outcrops as a linear NE-SW belt. Numerous metabasic bodies  
128 intrude the Radium Creek Group and are considered to be late Mesoproterozoic to Neoproterozoic  
129 in age (Wulser, 2009). Minor pegmatite lenses throughout the Radium Creek Group in the northern  
130 Mount Painter Inlier are most likely syn- to post- the Cambro-Ordovician Delamerian Orogeny  
131 (Elburg et al., 2003). Within the central part of the inlier, the peraluminous British Empire Granite  
132 and metaluminous Paralana Granodiorite are interpreted to have been emplaced during the  
133 Palaeozoic ca. 460-440 Ma (Elburg et al., 2003; McLaren et al., 2006).

134 1.3.4 Metasomatism

135 Lenses of peraluminous to hyperaluminous rock, composed of phlogopite-corrundum-kyanite  
136 bearing assemblages are present within the Radium Creek Group in the Mount Adams area proximal  
137 to the Mount Neill Granite (Shafton, 2006). This lithology is correlated with the Corundum Creek  
138 Schist Member (Shafton, 2006) originally mapped as part of the Radium Creek Metamorphics (Coats  
139 and Blissett, 1971). Elburg et al. (2011) interpreted these bodies as metasomatised igneous rocks  
140 which likely reflect intense alteration of the Mount Neill Suite.

141 1.3.5 Structure

142 The Inlier is bisected by the Paralana Fault Zone (Fig. 3) which separates sequences of the Radium  
143 Creek Group. This fault system is a major crustal-scale feature and has a predominantly steep,  
144 northwest-dipping geometry as interpreted from the 08GA-C1 deep seismic reflection survey (Korsch  
145 and Kositsin, 2010). Field observations indicate that the fault zone is defined by a corridor of high  
146 strain, which record demonstrable reactivations since the Early Mesoproterozoic (Armit et al., 2012)  
147 through to the Cenozoic (Elburg et al., 2012; Teasdale, 1993).

148 1.4 Approach of this study

149 Geochronology coupled with isotopic fingerprinting of ancient rock packages is a powerful tool for  
150 constraining reconstructions of Proterozoic terranes (e.g. Cawood et al. 1999; Halilovic et al. 2004;  
151 Nelson, 2001). This allows us to reconstruct links between cratonic elements with greater  
152 confidence, which improves global reconstructions.

153 This study aims to provide constraints on the timing and provenance of deposition of the Radium  
154 Creek Group. To achieve this we compare the isotopic and geochronological signatures of detrital  
155 zircon populations from these metasediments with that of neighbouring tectonic elements. Direct  
156 comparison of our new zircon age data with Precambrian terranes across eastern Australia can then  
157 be used to identify the most likely crustal element(s) those zircons, and thus sediments, are derived  
158 from.

159 In addition, the employment of trace element and Lu-Hf isotope system fingerprinting allows us to  
160 also compare the source (i.e. relative contemporary crust/mantle contribution) that different zircon  
161 populations have crystallised from (Blichert-Toft and Albarede, 1997). These data have the potential  
162 to discriminate between terranes that have similar chronology, but different magmatic source  
163 chemistry and antiquity, allowing a further level of discrimination between potential sources of  
164 detritus. Our approach is to assess the U-Pb-Hf-trace element signature of samples throughout the  
165 Radium Creek Group and compare them to that of zircon populations from potential source  
166 lithologies across a number of terranes, using both new data presented herein and published

167 datasets from the Gawler Craton, Mount Isa Inlier, Curnamona Province and Arunta Block  
168 (Belousova et al., 2006b; Condie et al., 2005; Griffin et al., 2006; Hollis et al., 2010; Howard et al.,  
169 2009; Howard et al., 2011a; Howard et al., 2011b; Howard et al., 2011c; Szpunar et al., 2011).

170 Available whole rock Nd isotope datasets from across the region (Neumann, 2001; Schaefer, 1993;  
171 Wade et al., 2012) are also examined in order to further test observed temporal and spatial patterns  
172 with respect to relative inputs of juvenile material, which can provide insights into the provenance of  
173 the Radium Creek Group.

#### 174 1.5 Samples

175 Four samples from the Mount Painter Inlier were investigated. Three of which (Z3, F and 123) are  
176 from the hanging wall (western side) of the Paralana Fault and one from the eastern (foot-wall) side  
177 (see Fig. 3). Sample Z3 is a sample of a fine-grained, mica rich, garnet + quartz psammopelitic  
178 horizon within the Brindana Schist (Fig. 4a-b). This horizon is located ~100 m to the west of the  
179 Paralana Fault and Mount Neill Granite Suite. Sample F is a medium-grained quartz + muscovite ±  
180 garnet layer within the Freeling Heights Quartzite ~6 km to the south-west of sample Z3 (Fig. 4c-d).  
181 123 is a coarse grained quartz + muscovite layer of the Freeling Heights Quartzite (Fig. 4e-f). This  
182 sample location is ~2 kilometres south-west of sample F. 36 is a medium grained quartz + muscovite  
183 ± biotite ± garnet layer of the Mount Adams Quartzite (Fig. 4g-h), from the eastern side of both the  
184 Paralana Fault and the Mount Neill Granite Suite.

185 Additionally, we studied one sample from the Central Gawler Craton. Sample YD23A is a black,  
186 coarse-grained porphyritic (plagioclase + k-feldspar + iron oxide) sample (Fig. 4i-j) of the Pondanna  
187 member of the Upper Gawler Range Volcanics (uGRV; Allen et al., 2003; Blissett et al., 1993). The  
188 uGRV is a major capping sequence of the Gawler Felsic Large Igneous Province (Allen et al. 2012),  
189 and is composed of widespread and homogeneous felsic lava (due to high magmatic temperature  
190 and halogen enrichment, promoting efficient mixing via low magmatic viscosity: see Pankhurst et al.  
191 2011a) that outcrops as monotonous sheets across the Central Gawler Craton. The emplacement of  
192 this voluminous felsic large igneous province (FLIP) was rapid (Pankhurst et al. 2011b), and occurred  
193 at ca.  $1592 \pm 3$  Ma (Fanning et al., 1988). As such, this sample represents both a snapshot of Gawler  
194 Craton evolution as well as the principle source of Gawler Craton-derived detritus, at the apparent  
195 time of Radium Creek Group deposition.

196 Finally, two samples are taken from drillholes ~150 kilometres to the south of the Mount Painter  
197 Inlier, within the Curnamona Province (Fig. 1b-c). They have previously been dated using in-situ  
198 zircon U-Pb techniques by Jagodzinski & Fricke (2010). Sample R1707876 is from the Frome 12  
199 Granite, Bimbowrie Suite, intersected in drillhole DDH Frome 12 (385176E, 6503512N). Sample

200 R1709059 is from rhyolite assigned to the Benagerie Volcanic Suite, intersected in DDH Frome 13  
201 (393612E, 66528251N). Both of these samples are from igneous rocks emplaced within the  
202 Curnamona Province at ca. 1594-1587 Ma (Jagodzinski and Fricke, 2010). They therefore contain  
203 information regarding the Early Mesoproterozoic evolution of the Curnamona Province, as well as  
204 representing a potential contemporary source for detritus contributing to the Radium Creek Group.

## 205 **2 Methods**

### 206 **2.1 Sampling for whole rock geochemistry and zircon extraction**

207 Several kilograms of representative material were collected from each site (see Fig. 3-4). Weathered  
208 rinds and any obvious zones of alteration were discarded. These samples were then pulverised using  
209 a ceramic disc mill and sieved to collect the resulting fragments within an 18 to 250  $\mu\text{m}$  size range.  
210 Magnetite within this fraction was removed using a hand magnet. Tetrabromoethane (TBE;  
211 2.96g/ml) and Di-iodomethane (DIM; 3.3g/ml) heavy liquids were then used to separate minerals  
212 with high specific gravity (including zircon) from the predominantly lighter medium. A further  
213 magnetic separation step followed using the heavy fraction. We used a Frantz magnetic separator  
214 set at 1.4 Amps, 15° forward and 25° side tilt.

### 215 **2.2 Zircon mounting, imaging and in-situ targeting**

216 Zircons were hand-picked from the non-magnetic fraction using a binocular microscope and  
217 suspended in an epoxy resin mount for grinding, polishing and carbon coating. The mounts were  
218 imaged using a JEOL JSM 6300 SEM at Ballarat University (both back scatter electron and cathode  
219 luminescence images) on the Brindana Schist sample (sample Z3), and a JEOL JSM-840A SEM (back  
220 scatter electron images only) at the Centre for Electron Microscopy, Monash University on the uGRV  
221 sample (YD23a). A Cameca SX100 electron microprobe (back scatter electron and  
222 cathodoluminescence images) was used to image zircons from the Freeling Heights Quartzite  
223 (sample F, 123), Brindana Schist (sample Z3) and Mount Adams Quartzite (sample 36) at GEMOC,  
224 Macquarie University. These images (BSE and/or CL) were used to choose analysis spots for each  
225 grain. The most appropriate sites were those that best fit the criteria of adequate size, internal  
226 consistency and tractable petrographic context of crystal zonation domains.

227

### 228 **2.3 Analytical methods**

#### 229 **2.3.1 In-situ major and trace element chemistry**

230 Electron microprobe (EMP) analysis for in-situ zircon major and trace-element ( $\text{HfO}_2$ ,  $\text{SiO}_2$ ,  $\text{ZrO}_2$ ,  
231  $\text{Y}_2\text{O}_3$ ) geochemistry was conducted on samples from the Freeling Heights Quartzite (samples F) and  
232 Mount Adams Quartzite (sample 36) using a Cameca SX100 Electron Microprobe fitted with 5

233 wavelength dispersive spectrometers (WDS) and Princeton Gamma-Tech (PGT) energy dispersive  
234 system (EDS). The microprobe was operated at an accelerating voltage of 15 kV with a beam current  
235 of 20 nA, a 1-2  $\mu\text{m}$  beam diameter, and a dwell time of 60 seconds acquisition after 60 seconds  
236 background. The analyses were conducted at the same site within each zircon grain chosen for both  
237 the U-Th-Pb-trace and Hf-isotope analyses.

### 238 2.3.2 U-Th-Pb

239 In-situ zircon U-Th-Pb isotope analysis was conducted at Macquarie University using a HP 4500  
240 quadrupole inductively coupled plasma mass spectrometer (ICPMS) attached to a New Wave UV213  
241 Laser system for samples Z3, F, 123 and 36. Analysis of zircon from sample YD23a was undertaken at  
242 Monash University by laser ablation (LA) -ICPMS attached to a Thermo X-series quadrupole coupled  
243 with a New Wave 213 nm, Nd: YAG laser. A laser spot size between 30-40  $\mu\text{m}$  was used depending  
244 on the size and morphological complexity of each zircon. Ablation sites were chosen to best  
245 represent populations from each of the distinct zircon morphologies that could be characterised  
246 from BSE and CL images of the zircon grains (see Fig. 5). The lasers at both Macquarie University and  
247 Monash University were operated using a 5 Hz repetition rate with 11-13  $\text{mJcm}^{-2}$  laser energy at the  
248 sample with a 60-120 s acquisition period including 15 ms dwell for  $\text{Pb}^{206}$ ,  $\text{U}^{238}$ ; 10ms for  $\text{Pb}^{204}$ ,  $\text{Pb}^{208}$ ,  
249  $\text{Th}^{232}$  and 30 ms for  $\text{Pb}^{207}$ . The dwell times for sample YD23a (undertaken on the Monash University  
250 LA-ICPMS) differed slightly with a shorter 10 ms dwell for  $\text{Pb}^{204}$  and 25 ms for  $\text{Pb}^{206}$ ,  $\text{Pb}^{207}$ ,  $\text{Th}^{232}$  and  
251  $\text{U}^{238}$ .

252

### 253 2.3.3 In-situ Lu-Hf

254 We targeted zircons for Hf isotope analysis that represented each distinct U-Pb age population  
255 within each sample. Hf isotopes were only measured from grains with U-Pb ages that were <10%  
256 discordant. The specific sites were chosen to be adjacent to the same pit and within the same  
257 internal domain, ablated for U-Pb isotopic analysis (identified by BSE and CL images: Fig. 5).

258 The in-situ zircon Lu-Hf isotope analytical technique used in this study follows that described by  
259 Griffin et al., (2004); Griffin et al., (2006); Griffin et al., (2002). Analysis was conducted at GEMOC,  
260 Macquarie University using a New Wave/Merchantek LUV213 (Nd: YAG) laser-ablation system  
261 attached to a Nu Plasma multicollector ICPMS via Ar/He gas delivery. The ICPMS was tuned using a 1  
262 ppm solution of the JMC475Hf standard spiked with 80 ppb Yb, which yielded a typical total Hf beam  
263 of  $10\text{-}14 \times 10^{-11} \text{ \AA}$  (Jackson et al., 2004).

264 The analyses in this study were carried out using a 40 to 55  $\mu\text{m}$  beam diameter with a 5Hz repetition  
265 rate and  $\sim 0.6$  mJ/pulse which produced a total Hf signal of  $1\text{-}6 \times 10^{-11}$  Å. Following 60 s of  
266 background measurement, 80-120 s of acquisition time per analysis produced  $\leq 50$   $\mu\text{m}$  deep pits.

267 During the analytical run, Mud Tank Zircon standard was analysed as an internal monitor (Table 1).  
268 These measurements yielded an average corrected  $^{176}\text{Hf}/^{177}\text{Hf}$  ratio of  $0.282527 \pm 0.000029$  ( $n=14$ ,  
269  $2\sigma$ ), which is within the error of the long term average  $0.282532 \pm 0.000033$  ( $n=984$ ,  $2\sigma$ ) and  
270  $0.282523 \pm 0.000043$  ( $n=2190$ ,  $2\sigma$ ) (Pearson, N.J. Pers comms, 2010). In addition, the 91500 zircon  
271 standard was analysed, and yielded a corrected average  $^{176}\text{Hf}/^{177}\text{Hf}$  ratio of  $0.282322 \pm 0.000059$   
272 ( $n=4$ ,  $2\sigma$ ) which is within error of the long term average of  $0.282307 \pm 0.000058$  ( $n=632$ ,  $2\sigma$ ) (from  
273 Pankhurst et al., 2013). In addition and where possible, multiple ablations of the same domain in  
274 our unknown samples (quasi repeat analyses) returned  $\varepsilon$  Hf values that were indistinguishable from  
275 the original analyses ( $1\sigma < 0.05 \varepsilon$  Hf).

#### 276 2.3.4 Whole-rock geochemistry

277 Splits ( $\sim 250$  g) of sample Z3 and sample F were crushed using a hydraulic press and then further in  
278 an agate mill to produce a powder of each sample. A portion (15 g) of each powder was analysed for  
279 major elements using a Bruker-AXS S4 Pioneer XRF Spectrometer and processed through Bruker-AXS  
280 Spectra-plus software, at the Advanced Analytical Centre at James Cook University. This is the same  
281 method and laboratory that determined the whole rock data from sample Y23a (see Pankhurst et al.  
282 2011a). Trace (including rare-earth element) data were acquired from high-pressure digestions using  
283 HF. This step was followed by an HCl digestion at one atmosphere before drying down and  
284 converting to nitric complexes using  $\text{HNO}_3$ . These samples were then taken up in dilute  $\text{HNO}_3$ , spiked  
285 with a Li, In and Bi internal standard before analysing the solutions using a quadrupole ICPMS at  
286 Monash University.

287

## 288 2.4 Data treatment

### 289 2.4.1 U-Th-Pb isotope ratios

290 U-Th-Pb isotopic ratios were calculated using GLITTER software (e.g. Van Archerbergh et al., 1999)  
291 and the U-Pb ages were calculated using Isoplot 4.15. The procedure for data reduction procedure  
292 follows that of Griffin (2004) and Jackson et al. (2004) and in each case GEMOC GJ-1 zircon (TIMS  
293 normalisation values of Jackson et al. (2004) are:  $^{207}\text{Pb}/^{206}\text{Pb}$  608.3 Ma,  $^{206}\text{Pb}/^{238}\text{U}$  600.7 Ma and  
294  $^{207}\text{Pb}/^{235}\text{U}$  602.2 Ma) was used to correct for U-Pb fractionation. In addition, the 91500 zircon  
295 standard was analysed within each run as a monitor of the reproducibility and accuracy for both  
296 LAM-ICPMS instruments used (Table 2). A correction for  $^{204}\text{Pb}$  was applied following the method

297 described in Anderson (2002). This correction had a negligible effect on the majority of the analyses.  
298 Absolute ages and their individual errors were calculated using Isoplot 4.15 (Ludwig, 2008), and age  
299 populations were assessed with the unmix function (to unmix superimposed Gaussian distributions)  
300 as appropriate.

#### 301 2.4.2 Zircon trace element data

302 A Cameca  $\Phi\rho z$  correction procedure was applied to the EMP dataset to calculate oxide percentages  
303 from raw counts. The trace element concentration data (Y, Hf) were combined with U, Th, Lu, Yb  
304 concentration data acquired during the LAM-ICPMS analysis, and used to model potential magmatic  
305 source rock type (c.f. Belousova et al., 2002) for each grain, and by extension, on age populations.  
306 These data were collated for selected grains from sample F (n=16) and sample 36 (n=18) that satisfy  
307 our selection criteria: grains were chosen to represent each of the U-Pb detrital age population  
308 brackets, and were limited to igneous crystals only, by using geochemical data as a filter (Th/U ratios  
309 of >0.5 normally indicate an igneous origin; Cowley and Fanning, 1992).

#### 310 2.4.3 Lu-Hf isotope ratios

311 Measured masses 172, 175, 176, 177, 178, 179 and 180 were normalised to  $^{179}\text{Hf}/^{177}\text{Hf} = 0.7325$   
312 using an exponential correction for mass bias. Interference of  $^{176}\text{Lu}$  on  $^{176}\text{Hf}$  was corrected using a  
313  $^{176}\text{Lu}/^{175}\text{Lu}$  ratio = 0.02669 (Claoué-Long et al., 2008) and measuring the interference-free  $^{175}\text{Lu}$  value  
314 to calculate  $^{176}\text{Lu}/^{177}\text{Hf}$ . Interference of  $^{176}\text{Yb}$  on  $^{176}\text{Hf}$  was corrected using a  $^{176}\text{Yb}/^{172}\text{Yb}$  ratio of  
315 0.5865 (see Griffin et al., 2000), determined by spiking the JMC475 Hf standard with Yb, and  
316 measuring the interference-free  $^{172}\text{Yb}$  (Jackson et al., 2004). Repeated analysis of standard zircons  
317 (see 3.2.3 above) with a variety of  $^{176}\text{Lu}/^{177}\text{Hf}$  and  $^{176}\text{Yb}/^{177}\text{Hf}$  ratios (see Griffin et al., 2004)  
318 establishes the accuracy and precision of the Lu and Yb corrections.

319 The measured  $^{176}\text{Lu}/^{177}\text{Hf}$  ratios for each of the zircons analysed were used to calculate initial  
320  $^{176}\text{Hf}/^{177}\text{Hf}$  ratios. Numerous proposed decay constants exist for  $^{176}\text{Lu}$  (e.g. Bizzarro et al., 2003;  
321 Blichert-Toft et al., 1997; Scherer et al., 2001; Soderlund et al., 2004). We have used a value of  
322  $1.865\text{E}^{-11}/\text{yr}$  for all Hf isotope calculations (Scherer et al., 2001; Soderlund et al., 2004). Chondritic  
323 values of  $^{176}\text{Lu}/^{177}\text{Hf} = 0.282772$  and  $^{176}\text{Hf}/^{177}\text{Hf} = 0.0332$  (Blichert-Toft and Albarede, 1997) are used  
324 for calculating  $\varepsilon_{\text{Hf}}$  and model ages.

325 The mean 2se precision of  $^{176}\text{Hf}/^{177}\text{Hf}$  ratios presented in this study is  $\pm 0.00002$  which equates to  
326  $\pm 0.7 \varepsilon_{\text{Hf}}$ . The majority of the analyses returned a 2se uncertainty range between <1-5%  
327 contributing an uncertainty of between 0.05 and 0.25  $\varepsilon_{\text{Hf}}$ . This uncertainty reflects the within-grain  
328 variation in Lu/Hf observed in zircons and the analytical uncertainties (Belousova et al., 2006a).

329 Further discussion on the precision and accuracy of this method are expanded upon in Griffin et al.  
330 (2002; 2004).

331 Calculation of depleted mantle model ages ( $T_{DM}$ ) for each zircon analysis were made using the  
332 measured  $^{176}\text{Lu}/^{177}\text{Hf}$  and modelled values for  $^{176}\text{Hf}/^{177}\text{Hf}_i = 0.279718$  at 4560 Ma and  $^{176}\text{Lu}/^{177}\text{Hf} =$   
333  $0.0384$  (Griffin et al., 2000). These values produce a depleted mantle model with  $^{176}\text{Hf}/^{177}\text{Hf}_{(\text{present-day})}$   
334  $= 0.28325$ , comparable to average MORB (Nowell et al., 1998). These single-stage model ages  
335 provide a minimum age on the source material from which the zircon crystallised. In addition, two  
336 stage model ages or crustal model ages ( $T_{DM}^c$ ) were calculated. These models assume that a zircon's  
337 parental magma was formed from average continental crust and therefore use a  $^{176}\text{Lu}/^{177}\text{Hf}$  ratio of  
338  $0.015$  (Griffin et al., 2004) (Geochemical Earth Reference Model database) that was initially derived  
339 from the depleted mantle.

### 340 **3 Results**

#### 341 **3.1 Zircon descriptions**

342 The zircon grains ( $n=57$ ) from sample Z3 are rounded and reddish-brown. Typical diameters range  
343 from 30 to 100  $\mu\text{m}$ . In  $\sim 90\%$  of these zircons, morphologies are characterised by oscillatory zoned  
344 cores (Fig. 5a-b) with isometric overgrowths and rims (6 rims  $>30 \mu\text{m}$  in thickness). The additional  
345 10% zircons have isometric morphologies with  $<15 \mu\text{m}$  overgrowths.

346

347 Zircons from sample F ( $n=138$ ) are predominantly brown, subhedral grains and are slightly larger  
348 than those in sample Z3 ( $\sim 80\% >70\mu\text{m}$ ). The morphology of these zircons is predominantly  
349 characterised by oscillatory zoned cores ( $\sim 75\%$  of grains) with variable, weak to strongly zoned rims  
350 and isometric overgrowths (Fig. 5c-d).

351

352 Grains of zircon separated from sample 36 ( $n=32$ ) are reddish-brown in colour and have a typical  
353 diameter range from 40-110  $\mu\text{m}$ . The grains are subhedral and  $\sim 80\%$  have oscillatory zoned cores  
354 (Fig. 5e-f). The remainder have isometric cores.  $\sim 10\%$  of the grains have very thin overgrowths ( $<10$   
355  $\mu\text{m}$ ).

356

357 The zircons separated from sample 123 ( $n=33$ ) are indistinct in terms of colour, shape and size from  
358 the grains in sample F. Approximately 90% of the grains have oscillatory zoned cores. Very thin ( $<10$   
359  $\mu\text{m}$ ) rims/overgrowths are apparent on  $\sim 30\%$  of the grains (Fig. 5g-h).

360

361 The zircon grains from sample YD23a ( $n=29$ ) are brown in colour, subhedral in shape, exhibit blunt  
362 pyramidal terminations, and vary in size between 100-300  $\mu\text{m}$ . All of the zircon grains from this

363 sample display oscillatory zonation and do not show any evidence for any metamorphic overgrowths  
364 (Fig. 5i-j).

365 Description of the Curnamona Province zircons from R1707876 (Frome Granite) and R1709059  
366 (Benagerie Volcanic Suite) can be found in Jagodzinski & Fricke (2010).

### 367 **3.2 U-Th-Pb zircon geochronology**

368 Results from LA-ICPMS U-Pb dating of zircon are presented in Table 3. The complete dataset is  
369 provided in Supplementary Appendix A. Probability density plots and concordia plots for each of the  
370 samples analysed in this study are shown in Fig. 6-7.

#### 371 3.2.1 Z3 (Radium Creek Group - Brindana Schist)

372 A total of 78 zircon U-Pb analyses were conducted on 60 separate zircon grains. Data were gathered  
373 from both the cores and regions with clear oscillatory zoning for completeness (Fig. 6a-b). Six  
374 analyses from this total dataset were interpreted as metamorphic zircon growth (see Armit et al.,  
375 2012). Armit et al. (2012) described these zircons as exhibiting isometric rims and overgrowths, yet  
376 only 3 of these analyses returned Th/U ratios  $<0.3$  (an order of magnitude lower than the detrital  
377 igneous zircon cores presented here) and were less than 10% discordant. These metamorphic  
378 overgrowths have weighted mean  $^{207}\text{Pb}/^{206}\text{Pb}$  age of  $1552 \pm 32$  Ma ( $2\sigma$ ).

379

380 Fifty-four analyses from the remaining 72 are within 10% concordancy. The probability density plot  
381 for this sample has two major zircon population peaks (Fig. 6). The younger population consists of a  
382 group of 19 zircons which have a weighted mean  $^{207}\text{Pb}/^{206}\text{Pb}$  age of  $1595.7 \pm 9.2$  Ma ( $n = 19$ , MSWD =  
383 0.38,  $2\sigma$ ). An older population of 21 zircons has a weighted mean  $^{207}\text{Pb}/^{206}\text{Pb}$  age of  $1708 \pm 17$  Ma ( $n$   
384 = 21, MSWD = 1.9,  $2\sigma$ ). This peak consists of two separate populations at ca. 1680 Ma and at ca.  
385 1740 Ma. Three zircons with an age range of between ca. 1790 and ca. 1850 Ma were present in the  
386 sample. Archaean to earliest Palaeoproterozoic aged detrital zircons were also present in the sample  
387 and exhibit an age range of between ca. 2370 and ca. 2900 Ma.

388

#### 389 3.2.2 F (Radium Creek Group – Freeling Heights Quartzite)

390 A total of 148 U-Pb zircon analyses were conducted for this sample across 138 grains. Four of these  
391 analyses were located on zircon overgrowths/rims with isometric and/or 'fir-tree' and/or sector  
392 zoned morphology that were  $>30\mu\text{m}$  wide, and therefore could return signals uncontaminated by  
393 neighbouring domains, these are discussed in Armit et al. (2012). One hundred of the analyses from  
394 the remaining 144 igneous detrital zircon fraction were within 10% concordancy. The probability  
395 density plot of concordant analyses ( $<10\%$  discordant) for this sample has 3 major peaks (Fig. 6c-d).

396 The youngest population consists of 17 zircon grains and has a weighted mean  $^{207}\text{Pb}/^{206}\text{Pb}$  age of  
397  $1591.7 \pm 7.8$  Ma ( $n=17$ , MSWD = 1.9,  $2\sigma$ ). An older peak is composed of two distinct populations  
398 (isoplot unmix routine) at ca. 1680 Ma and at ca. 1730 Ma. A single grain from this sample returned  
399 a ca. 1841 Ma age. Eighteen analyses returned an age plateau between 2240 Ma and 2600 Ma.

#### 400 3.2.3 123 (Radium Creek Group - Freeling Heights Quartzite)

401 U-Pb analysis was conducted on 40 separate detrital igneous-sourced zircons. Nine analyses were  
402 more than 10% discordant. Probability plots for the 31 remaining analyses are displayed in figure 6e-  
403 f. A tight cluster of late Mesoproterozoic zircon ages ( $n=8$ ) have a weighted mean  $^{207}\text{Pb}/^{206}\text{Pb}$  age of  
404  $1590 \pm 6$  Ma ( $n = 8$ , MSWD = 0.95,  $2\sigma$ ). The remaining, older ages are characterised by  
405 Palaeoproterozoic populations at ca. 1660 Ma, ca. 1710 Ma and 1770 Ma. An Earliest  
406 Palaeoproterozoic population is also present and returns a weighted mean  $^{207}\text{Pb}/^{206}\text{Pb}$  age of  $2490.1$   
407  $\pm 9.9$  Ma ( $n=4$ , MSWD = 0.41,  $2\sigma$ ).

#### 408 3.2.4 36 (Radium Creek Group – Mount Adams Quartzite)

409 Thirty-nine analyses were conducted on 38 zircon grains for U-Pb ages from this sample of the  
410 Mount Adams Quartzite (Fig. 6g-h). One analysis is >10% discordant. The youngest distinguishable  
411 population from the remaining 38 analyses is a cluster at  $1592 \pm 10$  Ma ( $n = 8$ , MSWD = 1.4,  $2\sigma$ ).  
412 Other population peaks are evident at ca. 1680 Ma, ca. 1710 Ma and ca. 1740 Ma. An older, Earliest  
413 Palaeoproterozoic population has a weighted mean  $^{207}\text{Pb}/^{206}\text{Pb}$  age of  $2477.1 \pm 11$  Ma ( $n=3$ , MSWD =  
414 2.2,  $2\sigma$ ).

#### 415 3.2.5 YD23a (upper Gawler Range Volcanics)

416 A total of 33 analyses were conducted on 29 separate zircons grains. 26 of these are  $\leq 10\%$   
417 discordant. No concordia age or intercept age could be satisfactorily determined using the entire  
418 population. In addition, the weighted mean  $^{207}\text{Pb}/^{206}\text{Pb}$  age for the entire group (Fig. 7) produced an  
419 MSWD >8. The very high MSWD implies the presence of inherited zircon populations. These are  
420 calculated using probability plots and unmixing models to have ages of ca. 1680 Ma and ca. 1760  
421 Ma. These analyses correlate with dark core regions in CL images, which independently suggest that  
422 they should not be included in a weighted crystallisation age calculation. Instead we prefer the  
423 weighted mean  $^{207}\text{Pb}/^{206}\text{Pb}$  age of  $1595 \pm 19$  Ma ( $n = 17$ , MSWD = 0.046,  $2\sigma$ ), which is consistent with  
424 the previously published age of the Yardea Dacite (upper Gawler Range Volcanics:  $1592 \pm 3$  Ma;  
425 Fanning et al., 1988) as well as the lower units of the Gawler Range Volcanics  $1591 \pm 3$  Ma (Fanning  
426 et al., 1988).

### 427 3.3 In-situ Lu-Hf

428 A total of 74 zircon grains were analysed from the Radium Creek Group. This included 37 grains from  
429 the pelitic Brindana Schist, 18 from the overlying Freeling Heights Quartzite and 19 from the Mount  
430 Adams Quartzite (Fig. 8a-b). Twenty-five grains were analysed from the upper Gawler Range  
431 Volcanics (Central Gawler Craton; YD23a) (Fig. 8c). Twenty-two grains with 2 repeats [from the same  
432 domain] were analysed from the Frome Granite (Fig. 8c), and 13 zircon grains from the rhyolitic  
433 Benagerie Volcanic Suite (Fig. 8c) (Curnamona Province; R1707876 and R1709059 respectively).  
434 These results are presented in Table 3 and summarised in Figure 8a-d (the full dataset is presented  
435 in Appendix A).

#### 436 3.3.1 Z3 (Radium Creek Group - Brindana Schist)

437 Hf isotope ratios measured from the ca. 2900 Ma (Archaean) zircon grain has a  $\varepsilon \text{Hf}_{(t)}$  value of +7.27  
438 and a crustal model age ( $T_{\text{DM}}^{\text{c}}$ ) of 2880 Ma (Fig 8a-b). Early Palaeoproterozoic zircon grains that are  
439 dated at 2300 and 2500 Ma have  $\varepsilon \text{Hf}_{(t)}$  of -4.89 and -1.11, and  $T_{\text{DM}}^{\text{c}}$  at 3110 Ma to 3240 Ma  
440 respectively (Fig. 8a-b). Zircon grains with ages between 1765 Ma and 1850 Ma (n=3) possess an  
441  $\varepsilon \text{Hf}_{(t)}$  range from -4.9 to -2.89 and  $T_{\text{DM}}^{\text{c}}$  ages between 2660 and 2800 Ma. Zircon grains with ca.  
442 1710-1760 Ma dates have initial  $\varepsilon \text{Hf}$  values that are scattered between -6.58 and +2.74 (n=6).  $T_{\text{DM}}^{\text{c}}$   
443 ages for these ca. 1710-1760 Ma zircons range from 2280 to 2840 Ma. A continuum of initial  $\varepsilon \text{Hf}_{(t)}$   
444 values from -4.21 to +5.8 characterise zircon grains with ages ca. 1630-1690 Ma (n=11) and  
445 correspond to  $T_{\text{DM}}^{\text{c}}$  ages between 2000 and 2630 Ma. The youngest population ca. 1595 Ma has a  
446  $\varepsilon \text{Hf}_{(t)}$  range between -6.7 and +2.77 (n=14) (Fig. 8a) and  $T_{\text{DM}}^{\text{c}}$  from 2150 to 2750 Ma (Fig. 8b).

#### 447 3.3.2 F (Radium Creek Group – Freeling Heights Quartzite)

448 The ca. 2500 Ma zircon grains (n=2) have  $\varepsilon \text{Hf}_{(t)}$  values of -5.15 and +1.29 ( $T_{\text{DM}}^{\text{c}}$  values of 3.38 and  
449 2970 Ma respectively) (Fig. 8a-b). A single grain with an age of ca. 1841 Ma has a  $\varepsilon \text{Hf}_{(t)}$  of -2.56 and  
450 a  $T_{\text{DM}}^{\text{c}}$  of 2680 Ma. A ca. 1730 Ma population s (n=8) records  $\varepsilon \text{Hf}_{(t)}$  values ranging from -9.4 to -0.53,  
451  $T_{\text{DM}}^{\text{c}}$  for this group are 2480 to 3030 Ma. Zircons with U-Pb ages of ca. 1680 Ma (n=3) have a range of  
452  $\varepsilon \text{Hf}_{(t)}$  values from -9.91 to 0 and  $T_{\text{DM}}^{\text{c}}$  from 2390 to 3000 Ma. An early Mesoproterozoic population  
453 ca. 1595 Ma (n=4) have  $\varepsilon \text{Hf}_{(t)}$  values ranging from -6.11 to +2.44 (Fig. 8a) and  $T_{\text{DM}}^{\text{c}}$  between 2170  
454 and 2720 Ma (Fig. 8b).

#### 455 3.3.3 36 (Radium Creek Group – Freeling Heights Quartzite)

456 This sample includes grains from 5 discrete age populations. All but the youngest (the early  
457 Mesoproterozoic population) have negative  $\varepsilon \text{Hf}_{(t)}$  values (Fig. 8a). The oldest grain ca. 2948 Ma has  
458 a  $\varepsilon \text{Hf}_{(t)}$  value of -9.46 and a  $T_{\text{DM}}^{\text{c}}$  of 3970 Ma. A ca. 2500 Ma population (n=2) has initial  $\varepsilon \text{Hf}$  values  
459 of -2.77 and -0.93 ( $T_{\text{DM}}^{\text{c}}$  values of 3220 and 3070 Ma respectively). Ca. 1850 Ma (n=2) zircon grains

460 have  $\varepsilon \text{Hf}_{(t)}$  values of -6.32 and -3.24 (Fig. 8a) with  $T_{\text{DM}}^{\text{c}}$  of 2730 and 2940 Ma respectively (Fig 8b).  
461 Grains at ca. 1710-1740 Ma (n=4) return a tight cluster of initial  $\varepsilon \text{Hf}_{(t)}$  values that range between -  
462 3.63 and -2.07. This group have  $T_{\text{DM}}^{\text{c}}$  from 2540 to 2670 Ma. A ca. 1677 Ma (n=3) population have a  
463  $\varepsilon \text{Hf}_{(t)}$  value range of -3.82 to -1.07 and  $T_{\text{DM}}^{\text{c}}$  between 2450 and 2630 Ma. A ca. 1595 Ma (n=7)  
464 population have a spread of  $\varepsilon \text{Hf}_{(t)}$  values ranging from -5.37 to +2.79 (Fig 8a) and corresponding  
465  $T_{\text{DM}}^{\text{c}}$  of 2130 to 2690 Ma (Fig 8b).

#### 466 3.3.4 YD23a (upper Gawler Range Volcanics)

467 This sample has 4 U-Pb age clusters. The principle age population (ca. 1595 Ma, n=20) ranges  
468 between -4.51 and -0.82,  $T_{\text{DM}}^{\text{c}}$  range of 2380-2620 Ma with an outlier that returned a  $\varepsilon \text{Hf}_{(t)}$  value of  
469 +3.01 and 2250 Ma  $T_{\text{DM}}^{\text{c}}$  (Fig. 8c).  $\varepsilon \text{Hf}_{(t)}$  of grains older than ca. 1710 Ma (n=4) range between +1.61  
470 and +2.81,  $T_{\text{DM}}^{\text{c}}$  ranges from 2300-2430 Ma.  $\varepsilon \text{Hf}_{(t)}$  values of ca. 1680 Ma (n=2) zircon grains are -1.14  
471 and -0.98,  $T_{\text{DM}}^{\text{c}}$  ages of 2440 and 2450 Ma (Fig. 8c).

#### 472 3.3.5 R1707876 (Curnamona Province: Frome Granite – Bimbowrie Suite)

473 The dominant population at  $1594 \pm 8$  Ma (n=22; Jagodzinski and Fricke, 2010) have  $\varepsilon \text{Hf}_{(t)}$  values  
474 ranging from -5.29 to +1.02 and  $T_{\text{DM}}^{\text{c}}$  between 2260 and 2670 Ma (Fig 8c). A single older grain ca.  
475 1640 Ma has an  $\varepsilon \text{Hf}_{(t)}$  value of -2.7 and  $T_{\text{DM}}^{\text{c}}$  of 2.53 Ga. A young grain ca. 1557 Ma has a distinctly  
476 positive  $\varepsilon \text{Hf}_{(t)}$  value of +5.96 and  $T_{\text{DM}}^{\text{c}}$  of 1920 Ma.

#### 477 3.3.6. R1709059 (Curnamona Province: Benagerie Volcanic Suite)

478 The single population ca. 1587 Ma calculated for this rhyolite (Jagodzinski and Fricke, 2010) recorded  
479 a range of  $\varepsilon \text{Hf}_{(t)}$  values from -1.7 to +4.0 and  $T_{\text{DM}}^{\text{c}}$  between 2070 and 2440 Ma (Fig. 8c).

### 480 **3.4 In-situ trace element chemistry**

481 The modelled rock type for each zircon analysed using the classification scheme of Belousova et al.  
482 (2002) are shown in Table 4 and are shown graphically in Figure 9. In both samples modelled (F and  
483 36), three modelled rock types for all of the zircons analysed were distinguished. These were low  
484  $\text{SiO}_2$  granitoids, granitoids (70-75 wt%  $\text{SiO}_2$ ) and dolerites.

485 The ca. 1595 Ma zircons in sample F (Freeling Heights Quartzite) were modelled as originating from  
486 low  $\text{SiO}_2$  granitoids (n=2) and from moderate  $\text{SiO}_2$  content (70-75 wt%) granitoids (n=1). The ca.  
487 1650-1680 Ma population was modelled as dolerite and 70-75 wt% granitoid (n=2). A subset of 8  
488 zircons from the ca. 1700-1740 Ma zircon population indicates a predominantly granitoid source  
489 rock (n=5), although two zircons modelled as being sourced from dolerite (n=2) and 1 from a low  
490  $\text{SiO}_2$  granitoid. The ca. 1800-1850 Ma and earliest Palaeoproterozoic populations were modelled as  
491 wholly 70-75 wt%  $\text{SiO}_2$  granitoid derived. The overall modelled rock type source distributions for this

492 sample are 62.5% granitoid (70-75 wt% SiO<sub>2</sub> content) derived (n=10/16) and 18.75% from both  
493 dolerite and low SiO<sub>2</sub> (<65 wt%) granitoids.

494 The ca. 1595 Ma zircons in sample 36 (Mount Adams Quartzite) model as being derived from both  
495 low (n=2) and moderate (n=3) SiO<sub>2</sub> content granitoids. The ca. 1650-1680 Ma grains in this sample  
496 are evenly sourced from dolerite and 70-75 wt% SiO<sub>2</sub> granitoid rock types, which is identical to  
497 sample F. The ca. 1700-1740 Ma grains in this sample (n=3) are similar to those from that in sample  
498 F, as two are modelled as granitoid (70-75 wt% SiO<sub>2</sub>), and the third as dolerite sourced zircon, but  
499 lack zircons derived from low SiO<sub>2</sub> granitoids. It is possible this is due to sample size. One zircon in  
500 the 1800-1850 Ma population is derived from a low silica granitoid, and the other to a moderate SiO<sub>2</sub>  
501 content granitoid. The Archaean portion of the zircons analysed from this sample are sourced from a  
502 granitoid with 70-75 wt% SiO<sub>2</sub> content (n=3) or from a dolerite (n=1). The total modelled rock type  
503 source distributions for this sample was 61.1% granitoid (70-75 wt% silica content) derived  
504 (n=11/18), 22.2% dolerite derived (n=4/18) and 16.67% from low silica granitoids (n=3/18).

### 505 **3.5 Whole rock geochemistry**

506 Complete major and trace element data is presented in supplementary appendix B. Major element  
507 data defines sample Z3 as shale and sample F as subarkose according to the classification of Herron  
508 (1998). Th/Sc ratios for each of sample Z3 and sample F are 2.506 and 2.23 respectively. The samples  
509 display negative Eu/Eu\* anomalies (Taylor & McLennan, 1985) of 0.41 for sample Z3 and 0.575 for  
510 sample F. Sample Z3 has a La/Yb<sub>n</sub> value of 6.05 and sample F has a value (La/Yb<sub>n</sub>) value of 1.08.

## 511 **4 Discussion**

### 512 **4.1 Implications of new Radium Creek Group U-Pb zircon ages**

513 In-situ U-Pb zircon dating of the Radium Creek Group units yielded a distinct Early Mesoproterozoic  
514 population within analytical uncertainty of each other. The 4 samples in this study yield a weighted  
515 mean average <sup>207</sup>Pb/<sup>206</sup>Pb age of 1595.5 ± 3.7 Ma (n=41), which can be interpreted as the maximum  
516 depositional age of the Radium Creek Group. This robust age is within error of the SHRIMP IIe U-Pb  
517 maximum depositional ages of 1600 ± 8 Ma (Palaeoproterozoic suite 4; Teale, 1993) and 1591 ± 6  
518 Ma (Palaeoproterozoic suite 5; Teale, 1993) for quartzofeldspathic gneisses sampled in the Paralana  
519 Creek ~10 kilometres to the south of the current study (Fraser and Neumann, 2010). Since we find  
520 these early Mesoproterozoic depositional ages to be prominent throughout the Radium Creek  
521 Group, we interpret a geological framework involving a single phase of deposition for the entire  
522 package (Coats and Blissett, 1971; Elburg et al., 2001) at ca. 1595 Ma rather involving two distinct  
523 phases as previously interpreted (Paul, 1998; Teale 1993). This single depositional episode model is  
524 consistent with the structural framework interpreted by Armit et al. (2012) who described an

525 upwards coarsening sequence from basal pelitic units (Brindana Schist) conformably overlain by  
526 quartzites and conglomerates of the Freeling Heights Quartzite (Fig. 10).

527 The overall detrital zircon U-Pb population distributions (Fig. 6) for all 4 Radium Creek Group  
528 samples in this study, are very similar to each other; with significant U-Pb age contributions at ca.  
529 1595 Ma, ca. 1660-1680 Ma, ca. 1710-1780 Ma and ca. 2500 Ma. Moreover, the in-situ zircon  
530 geochemistry of zircons from both the hanging wall (Freeling Heights Quartzite; sample F) and the  
531 footwall (Mount Adams Quartzite; sample 36) of the Paralana Fault is remarkably similar (Fig. 9).  
532 Modelling of these zircon grain's geochemistry classifies the population as predominantly derived  
533 from felsic magmatism, but both units also have a small component of more mafic derived magmatic  
534 zircons of ca. 1660-1680 Ma and ca. 1710-1780 Ma age.

535 Our data support the suggestion of comparable provenance for these units, and by extension, the  
536 Radium Creek Group across the fault. The most straightforward explanation is that entire group  
537 shares the same provenance. On this basis we interpret a source terrane for the Radium Creek  
538 Group that contains ca. 1595 Ma intermediate to felsic magmatic rocks and reworked older  
539 Archaean to Palaeoproterozoic mafic to felsic magmatic material.

540 In addition, a subordinate U-Pb population at ca. 1850 was discovered in both the Freeling Heights  
541 Quartzite (Sample F) and the Mount Adams Quartzite (sample 36). These quartzites have been  
542 previously interpreted as distinct units; the Mount Adams Quartzite forming an older unit in the  
543 stratigraphy (Coats and Blissett, 1971). The lower Freeling Heights Quartzite has also been  
544 interpreted to be significantly older than the upper Freeling Heights Quartzite and Mount Adams  
545 Quartzite on the basis of stronger deformation recorded in these lower horizons (Paul et al., 1999).  
546 Our data suggest these differences in deformation intensity may be due to factors other than a time  
547 break, as the indistinguishable maximum depositional ages for these two units and the similarities in  
548 both the dominant and subordinate U-Pb detrital populations (i.e. ca. 1850 Ma) would suggest that  
549 these quartzites are likely to be lateral correlatives to each other. The greater deformation intensity  
550 observed within the lower parts of the Freeling Heights Quartzite could instead be explained by the  
551 location of the Freeling Heights Quartzite in the hangingwall of the Paralana Fault, whilst the Mount  
552 Adams Quartzite is restricted to the footwall (Fig. 3). Strain partitioning related to protracted  
553 shearing along the Paralana Fault is suggested to result in the development of more intense  
554 deformation in the proximal parts of hangingwall to the fault.

555 The lower horizons of the Freeling Heights Quartzite are slightly more micaceous than the upper part  
556 of the unit and to the Mount Adams Quartzite (Armit, 2007). In particular, proximal to the contact

557 with the underlying Brindana Schist, the Freeling Heights Quartzite contains large micaceous pods in  
558 which strain has been localised during Mesoproterozoic and Palaeozoic deformation (Armit et al.,  
559 2012) producing a stronger structural fabric than is evident at the meso-scale in the upper horizons  
560 of the Freeling Heights Quartzite and in the Mount Adams Quartzite. According to this single  
561 deposition framework the entire ca. 1595 Ma Radium Creek Group is deformed by ca. 1591-1585 Ma  
562 deformation and is not sub-divided into pre- and post-deformational sequences (c.f. Fanning et al.,  
563 2003; Paul, 1998; Paul et al., 1999).

#### 564 **4.2 Whole rock geochemistry**

565 Th/Sc ratios for sample Z3 and sample F are higher than Post Archaean Australian Shale (PAAS,  
566 The/Sc = 0.91; Taylor & McLennan, 1985) which supports the interpretation from the in-situ zircon  
567 geochemistry that both of these samples were most likely sourced from a region dominated by felsic  
568 material (Bhatia & Cook 1986; Cullers & Berendsen 1998). The samples display moderately negative  
569 Eu/Eu\* anomalies (0.41 for sample Z3 and 0.575 for sample F) when compared to PAAS (0.65; Taylor  
570 & McLennan, 1985). This indicates their source was also characterised by negative Eu anomalies, a  
571 ubiquitous affinity of A-type magmatic suites. La/Yb<sub>n</sub> ratios of 6.05 for sample Z3 indicate it is slightly  
572 LREE enriched. Sample F displays significant HREE enrichment (La/Yb<sub>n</sub> value of 1.08), which is most  
573 likely due to accumulation of previously mobile HREE in garnets that grew as a result of regional  
574 metamorphism at ca. 1591-1552Ma (Armit et al. 2012).

#### 575 **4.3 In-situ Hf Isotopes**

576 Hf isotope signatures of the Radium Creek Group samples are fairly diverse and most likely reflect  
577 both less evolved and substantially more evolved signatures (Fig. 8a-b). Within each U-Pb age  
578 population, considerable overlap in the Hf isotope ratios is present across the three Mount Painter  
579 samples (Table 3). These data strengthens the argument that both the pelitic and more quartz-rich  
580 units of the Radium Creek Group are of the same provenance.

581 The ca. 1595 Ma U-Pb population within the Radium Creek Group samples (n=25, this study) in the  
582 northern Mount Painter Inlier is consistent with the spread in Hf isotope ratios of the Early  
583 Mesoproterozoic aged grains (n=4) in sample ARK661 (Fig. 8c-d), from the southern Mount Painter  
584 Inlier (Elburg et al. 2012). This strengthens for the interpretation of a similar provenance for all of  
585 the Early Mesoproterozoic metasediments in the Mount Painter Inlier. Our larger dataset both  
586 confirms the maximum depositional age for the Radium Creek Group, and demonstrates for the first  
587 time a clear bimodal  $\epsilon$  Hf<sub>(t)</sub> signature for this population. Mixing between an evolved component  
588 ( $\epsilon$  Hf<sub>(1595)}</sub> -6.7 to -1.17, n=16) and a more juvenile component ( $\epsilon$  Hf<sub>(1595)}</sub> 0 to +2.79, n=9) is consistent  
589 with this pattern (Fig. 8d).

590 The magmatic pulse that generated the detrital source material of the Radium Creek Group must  
591 have contained a juvenile component, but also recrystallised more evolved material.  
592 Contemporaneous melting of various mantle and crust is consistent with the bimodal Hf isotope  
593 data in the resultant sedimentary packages. The Early Mesoproterozoic U-Pb age population peak  
594 (ca. 1595 Ma) within the age spectra of neighbouring felsic-dominated magmatic rocks; the upper  
595 Gawler Range Volcanics (sample YD23a), Frome Granite and Benagerie Volcanic Suite, therefore  
596 invite  $\varepsilon \text{Hf}_{(t)}$  comparison with the Radium Creek Group (Fig. 8c).

597 The predominantly negative  $\varepsilon \text{Hf}_{(1595\text{Ma})}$  values (-4.51 to -0.82) of the upper Gawler Range Volcanics  
598 zircons (Fig. 8c) would suggest (prima facie) that it was formed from moderately evolved crustal  
599 material. However the single, positive  $\varepsilon \text{Hf}_{(1595\text{Ma})}$  value implies more juvenile material was also  
600 involved to a degree. Pankhurst et al. (2013) report whole-rock Hf data for the small volume mafic  
601 components of the Gawler Range Volcanics which record a more primitive signal than we observe  
602 within our zircon population. This demonstrates that a juvenile component of the Gawler Range  
603 Volcanics can be detected, and that its weak contribution to subsequent basin detritus may be  
604 muted by lack of mafic outcrop in the hinterland.

605 The Hf isotope signature of the upper Gawler Range Volcanics is similar to that of the ca. 1595 Ma  
606 detrital zircons from the Radium Creek Group, as their absolute range of  $\varepsilon \text{Hf}_{(1595\text{Ma})}$  values overlap  
607 (Fig. 8c). However, the Radium Creek Group data extends to both more evolved and strongly  
608 negative  $\varepsilon \text{Hf}_{(1595\text{Ma})}$  values. This might reflect a sampling bias (e.g. Andersen et al. 2005) or that the  
609 source terrane of the Radium Creek Group ca. 1595 Ma zircon peak has a greater isotopic  
610 heterogeneity than the preserved Gawler Range Volcanics alone.

611 Zircon grains with ca. 1595 Ma ages from the Frome Granite (Bimbowrie Suite) indicate that this  
612 magma formed at least in part from reworked crust of ca. 2260-2670 Ma (Fig. 8c). The signature is  
613 similar to the range of  $\varepsilon \text{Hf}_{(1595\text{Ma})}$  values from the upper Gawler Range Volcanics grains, as they also  
614 record predominantly negative values to weakly positive (-5.29 to +1.02) (Fig. 8c). Similarly, this  
615 range of values falls within that of the Radium Creek Group. Importantly, >1650 Ma U-Pb  
616 populations are absent from our data. Moreover the Frome Granite intrusive age of  $1594 \pm 8$  Ma  
617 (Jagodzinski and Fricke, 2010) would suggest that it would have been located within the crustal pile  
618 during the earliest Mesoproterozoic and hence unlikely to be actively eroding to provide the  
619 required detritus into a nascent ca. 1595 Ma basin now preserved in the Mount Painter Inlier.

620 The Hf isotope signature of the ca. 1595 Ma zircon populations in the Benagerie Volcanic Suite  
621 sample is defined by a relatively tightly clustered group of  $\varepsilon \text{Hf}_{(1595\text{Ma})}$  values (-1.73 to +4.0). This

622 group is appreciably more juvenile than the values for the upper Gawler Range Volcanics and Frome  
623 Granite (Fig. 8c). It is important to note that unlike the Radium Creek Group, we did not detect a  
624 more evolved and negative Hf component (-6 to -2) in this sample of Benagerie Volcanic Suite (Fig.  
625 8c).

626 The lack of a good match between the Benagerie Volcanic Suite and Radium Creek Groups zircon Hf  
627 isotope signature (Fig. 8c) implies that provenance of the metasediment within the Mount Painter  
628 Inlier is unlikely to include the Benagerie Volcanic Suite. The ca. 1587 Ma crystallisation age  
629 calculated for this sample (Jagodzinski and Fricke, 2010) is also slightly younger than the maximum  
630 deposition age (ca. 1595 Ma) of the Radium Creek Group (although within analytical uncertainty).  
631 Rather, this age has greater similarity with the age of the Mount Neill Suite magmatism in the Mount  
632 Painter Inlier (ca. 1585 Ma). This suite intrudes the metasediments following an episode of burial  
633 and deformation at ca. 1595-1585 Ma (Armit et al., 2012). Thus if the Benagerie Volcanic Suite are  
634 extrusive equivalents of the magmatic pulse that generated the Mount Neill Suite, it would not be  
635 feasible for these rocks to contribute to the source of the Radium Creek Group.

636 Thus a combination of Hf isotope data and geologic evidence, effectively remove the Curnamona  
637 Province felsic magmatic rocks with ca. 1595 ages (Frome Granite and Benagerie Volcanic Suite)  
638 from consideration as potential sources of the Radium Creek Group. The remaining sample is the  
639 Gawler Range Volcanics sample. The following discussion aims to explore this hypothesis.

640 The prominent ca. 1680-1660 Ma detrital zircon U-Pb population within the Radium Creek Group has  
641 a grouped  $\varepsilon_{\text{Hf}(t)}$  value range of -9.91 to +5.8 (n=17). A similar spread of values is evident in ARK661  
642 (Elburg et al., 2012) with  $\varepsilon_{\text{Hf}(t)}$  values of between -7 to +6.7 (n=9) (Fig. 8c-d). A source terrane for  
643 this scattered and highly variable Hf isotope signature is likely to be composed of reworked,  
644 refractory ca. 3000-2400 Ma Archaean to Palaeoproterozoic crust which has mixed with significantly  
645 more isotopically primitive material ca. 1680-1660Ma.

646 Two zircons from the upper Gawler Range Volcanics have U-Pb ages ca. 1655 Ma and therefore  
647 match the age peak within the Radium Creek Group. These two grains record slightly negative  $\varepsilon_{\text{Hf}(t)}$   
648 values. While these are within the  $\varepsilon_{\text{Hf}(t)}$  range for the corresponding Radium Creek Group age peak;  
649 it is difficult to ascribe much significance given the size of the data subset.

650 No pre-1650 Ma U-Pb population was identified from either the Frome Granite or Benagerie  
651 Volcanic samples (Jagodzinski and Fricke, 2010). It is worth noting that the absence of a ca. 1660-  
652 1680 age peak in these samples strengthens the argument that the pre-1650 Ma zircons in the  
653 Radium Creek Group cannot have been sourced from these magmatic suites.

654 Detrital zircons that define a U-Pb population at ca. 1710-1780 Ma in the Radium Creek Group have  
655 a relatively evolved Hf isotopic signature, although an appreciably juvenile signal is also present  
656 ( $\epsilon \text{ Hf}_{(t)}$  ranges between -9.4 to +2.74; n=18). Any potential sources for this detritus are interpreted to  
657 be composed of predominantly reworked and refractory ca. 3030-2680 Ma Archaean to  
658 Palaeoproterozoic crust that has mixed with slightly more isotopically juvenile material ( $T_{\text{DM}}^{\text{c}}$  of 2280  
659 Ma) at ca. 1710-1780 Ma.

660 The three zircons ca. 1710-1780 Ma from the upper Gawler Range Volcanics all record positive  $\epsilon \text{ Hf}_{(t)}$   
661 (+1.61 to +2.73), which is similar to the small (n=2; +0.08, +2.73) juvenile component within the ca.  
662 1710-1780 Ma Brindana Schist of the Radium Creek Group (Fig. 8c). Unlike the Radium Creek Group  
663 however, we did not detect a more evolved Hf component of ca. 1710-1780 Ma age in sample  
664 YD23a. Larger U-Pb-Hf zircon datasets for the upper Gawler Range Volcanics may resolve this Hf  
665 isotope mis-match.

666 All of the ca. 1850 Ma zircons analysed (n=4) from the Radium Creek Group in this study have  
667 isotopically evolved Hf signatures, interpreted as reworked ca. 2680-2940 Ma Archaean material  
668 (Fig. 8a). The six Hf isotope analyses from ca. 2500 Ma zircon grains have a  $\epsilon \text{ Hf}_{(t)}$  value range  
669 between -5.15 and +1.29 reflecting reworked >2970 Ma Archaean crust. Archaean zircon in sample  
670 ARK661 (n=5) have overlapping to moderately more juvenile Hf isotopic signatures with respect to  
671 the other sample of Radium Creek Group and are characterised by  $\epsilon \text{ Hf}_{(t)}$  values ranging between -  
672 0.35 and +4.12 (Fig. 8d) ( $T_{\text{DM}}^{\text{c}}$  range of 2820-3110 Ma). This most likely reflects a large isotopic  
673 heterogeneity in the Archaean component of the source terrane for the metasediments in the  
674 Mount Painter Inlier.

675 It is important to note the small sample populations of zircon grains (n <4) representing the ca.  
676 1710-1780 Ma and ca. 1850 Ma ages. It is therefore possible that the Hf isotopic signatures of these  
677 populations may not be truly representative.

#### 678 **4.4 Whole rock Nd isotopes**

679 Whole rock Nd isotope ratios of the Freeling Heights Quartzite and Yaglin Phyllite units of the  
680 Radium Creek Group (Neumann, 2001; Schaefer, 1993) have been recalculated to 1595 Ma to reflect  
681 the maximum depositional age of these units determined in this study. The result is negative  
682  $\epsilon \text{ Nd}_{(1595)}$  values of -5.19 to -3.25 (Freeling Heights Quartzite) and -4.36 (Yaglin Phyllite). This is  
683 consistent with the predominantly negative in-situ Hf isotopic signature presented in this study for  
684 the ca. 1595 Ma Radium Creek Group.

685 The  $\epsilon\text{Nd}_{(1585)}$  values of the felsic upper Gawler Range Volcanics range from -4.3 to -1.8, and as such  
686 are indistinguishable from those of the Benagerie Volcanic Suite (Wade et al., 2012). The felsic rocks  
687 of the lower Gawler Range Volcanics contain more variable values of  $\epsilon\text{Nd}_{(1585)}$ , and range from  
688 evolved ( $\epsilon\text{Nd}_{(1585)}$  of -7) to less evolved ( $\epsilon\text{Nd}_{(1585)}$  of -0.2) signals (Wade et al., 2012). The Radium  
689 Creek Group contains slightly more evolved  $\epsilon\text{Nd}_{(1595)}$  (e.g. -5.19 for the Freeling Heights Quartzite)  
690 and disperse  $\epsilon\text{Hf}_{(1595)}$  values than the upper Gawler Range or Benagerie Volcanic Suite. We suggest  
691 that isotopic correlation between the Radium Creek Group and the more diverse negative  $\epsilon\text{Nd}_{(1585)}$   
692 values for the lower Gawler Range Volcanics is more consistent.

693 The in-situ zircon age spectra and contained  $\epsilon\text{Hf}_{(t)}$  coupled with geologic context and whole-rock  
694  $\epsilon\text{Nd}$  support a Gawler Craton dominated provenance for the Radium Creek Group. The Curnamona  
695 Province contains appropriate felsic magmatic rocks of a similar age to that of the maximum Radium  
696 Creek Group deposition age, however, several lines of evidence preclude a Curnamona Province  
697 provenance for the Radium Creek Group.

#### 698 **4.5 Comparison with regional datasets**

699 The present location of the Mount Painter Inlier within the northern South Australia Craton (Fig. 1a-  
700 b) and relative proximity to both the Curnamona Province and the Gawler Craton (Fig. 1c) merits  
701 isotopic comparison between these terranes and with the North Australian Craton. Disperse U-Pb-Hf  
702 isotopic signatures from the detrital zircons in the Radium Creek Group supports a more complex  
703 provenance than from any one of the proximal magmatic suites (e.g. upper Gawler Range Volcanics,  
704 Frome Granite and Benagerie Volcanic Suite) analysed in this study (Fig. 8c).

705 The combined detrital zircon patterns of the Radium Creek Group strongly argue for provenance  
706 from a terrane that includes ca. 1595 Ma, ca. 1660-1680 Ma, ca. 1710-1780 Ma, 1850 Ma and  
707 Earliest Palaeoproterozoic to Archaean magmatic rocks or significant inherited populations. Major  
708 magmatic events in eastern Early Mesoproterozoic Australia ca. 1595 Ma are also recorded in the  
709 Arunta Inlier with the ca. 1603-1615 Ma Burt-Rungtjirba Suite (Zhao and McCulloch, 1995; Zhao  
710 and Bennett, 1995), in the Musgrave Block with the Musgravian Gneiss (Gum and Belousova, 2006;  
711 Kirkland et al., In Press; Wade et al., 2006), and in the Curnamona Province with the ca. 1600-1570  
712 Ma Mundi Mundi, Cusin Creek plutons, Benagerie Volcanic Suite and Ninnerie Supersuite (Fanning et  
713 al., 1998; Jagodzinski and Fricke, 2010; Wade et al., 2011;2012). The Gawler Craton magmatism ca.  
714 1604-1583 Ma is dominated by the voluminous felsic Gawler Range Volcanics and Hiltaba Suite  
715 (Fanning et al., 1988; Fanning et al., 2007) and localised deposition of clastic sediments (e.g. the  
716 upper Corunna Conglomerate) (Daly et al., 1998). Sedimentation in the Early Mesoproterozoic is  
717 also recorded across the North Australian Craton including the Upper McNamara Group in the

718 Mount Isa Inlier (Andrews, 1998; Krassay et al., 2000), the Favenc Package in the McArthur River  
719 area (Rawlings, 1999) and the Dargalong Metamorphics in the Georgetown Inlier (Withnall et al.,  
720 1997) (Fig. 1b).

721 Palaeoproterozoic basin evolution is widespread and broadly comparable across eastern Australia  
722 characterised by the Leichhardt, Calvert and Isa Superbasins in the Mount Isa Inlier (Jackson et al.,  
723 2000), the Etheridge Group in the Georgetown Inlier (Withnall et al., 1988), Willyama Supergroup in  
724 the Curnamona Province (Conor and Preiss, 2008), and the metasediments preserved in the central  
725 and northern Gawler Craton (Hand et al., 2007; Payne et al., 2006; Szpunar et al., 2011). The basins  
726 in the Curnamona and Gawler Craton have been interpreted to have a predominantly evolved, felsic  
727 magmatic ca. 1710-1780 Ma Arunta (Barovich and Hand, 2008; Payne et al., 2006) or northern  
728 Gawler Craton provenance (Howard et al., 2011c). Hf isotope datasets that include these 1710-1780  
729 Ma metasediments and felsic intrusives from the Fowler, Spencer, Olympic domains (Fig. 1c) of the  
730 Gawler Craton (Fig. 11a-b) (Belousova et al., 2009; Howard et al., 2011a; Howard et al., 2011b;  
731 Howard et al., 2011c; Szpunar et al., 2011) closely correlate with the felsic derived 1710-1780 Ma  
732 zircons in the Radium Creek Group. This would suggest that ca. 1710-1780 Ma detrital zircons in the  
733 Radium Creek Group could have been sourced from felsic intrusives in the Gawler Craton (e.g. ca.  
734 1736 Ma Middle Camp Granite and ca. 1755 Ma Wertigo Granite; Fanning et al. 2007; see Fig. 1c),  
735 re-worked ca. 1710-1780 Ma metasediments (e.g. Wallaroo Group and Moonabie Formation; see  
736 Fig. 1c) in the Gawler Craton, or from their protoliths in the northern Gawler Craton or Arunta Block.

737 However, potential ca. 1595 Ma felsic magmatic protoliths in the Arunta Block, such as the Burt-  
738 Rungtjirba Suite (Zhao, 1994) which has  $\epsilon_{\text{Nd}(1603-1615)}$  values of +0.91 to +2.49 is interpreted to be  
739 too juvenile to be a likely source of more evolved ca. 1595 Ma detritus in the Radium Creek Group.  
740 Moreover, comparison of the Hf isotopes of the Radium Creek Group detrital zircons with those of  
741 the Meso-Palaeoproterozoic Arunta Inlier (Hollis et al., 2010) shows little correlation between the  
742 disperse and generally negative, evolved  $\epsilon_{\text{Hf}(t)}$  in zircon characteristics of the Radium Creek Group  
743 and the predominantly juvenile  $\epsilon_{\text{Hf}(t)}$  values for zircons from the Arunta region (Fig. 12a). This would  
744 imply that the direct ca. 1595 Ma source of the detritus in the Mount Painter Province is unlikely to  
745 be the Arunta Block but does not preclude the incorporation and assimilation of ca. 1710-1760 Ma  
746 Arunta derived material with more refractory Archaean to Palaeoproterozoic crust, in the potential  
747 source terrane for the Radium Creek Group.

748 Correlation of the Radium Creek Group with the available Hf isotopic datasets (modern drainage  
749 samples) for the Curnamona Province (Condie et al., 2005) (Fig. 12b) and Mount Isa Inlier (Griffin et  
750 al., 2006) (Fig. 12c) is plausible. The dataset for the Broken Hill Block of the Curnamona Province

751 however, does not include any analysis of older Early Palaeoproterozoic or Archaean zircon grains  
752 (Fig. 12b). A number of authors (e.g. Cooper, 1985; Page et al., 2005) have indicated the existence of  
753 Archaean to Palaeoproterozoic zircon populations in the Curnamona Province, but further Hf isotope  
754 work is required to provide robust comparison with the pre-1700 Ma zircons in the Radium Creek  
755 Group. The Late Palaeoproterozoic to Early Mesoproterozoic zircon grains that constitute this  
756 Broken Hill dataset (Fig. 12b) are characterised by predominantly more juvenile Hf isotopic values  
757 than the Radium Creek Group. This more isotopically juvenile Hf range is consistent with the  
758 primitive  $\epsilon\text{Nd}_{(1650)}$  values of -3 to 0 reported by Barovich et al. (2008) for the upper Willyama  
759 Supergroup for which a distinct south-western Laurentia (Barovich et al., 2008) or southwest Baltica  
760 (Howard et al. 2011a) provenance has been proposed.

761 The U-Pb ages and Hf isotopic compositions from Mount Isa Inlier (Griffin et al., 2006) and Mount  
762 Painter Province metasediments reflect both Archaean and Palaeoproterozoic phases of crustal  
763 reworking (Fig. 11c). Mesoproterozoic magmatism in the Mount Isa Inlier did not initiate until ca.  
764 1550 Ma with the emplacement of the Williams and Narku Batholiths (Page and Sun, 1998). It is  
765 therefore problematic to consider any major magmatic suites in the Mount Isa Inlier as the source of  
766 the dominant ca. 1595 Ma magmatic derived zircon population in the Radium Creek Group.

767 Instead, it is plausible that the ca. 1595 Ma zircons in the Radium Creek Group could have been  
768 derived from  $1595 \pm 6$  Ma,  $1589 \pm 3$  Ma minor tuffaceous horizons in the Lawn Hill Formation and  
769 Balbirini Dolomite of the McArthur Basin (Page et al., 2000). However they would most likely  
770 represent volumetrically insignificant contributions if the Mount Isa Inlier or McArthur Basin were  
771 actively eroding ca. 1595 Ma and shedding material into the Mount Painter Province. The zircon  
772 budget from these tuffs would likely be swamped by competing sources.

773 A paucity of isotopically juvenile felsic magmatism ca. 1660-1680 Ma in eastern Proterozoic Australia  
774 reduces potential source correlations for the Radium Creek Group. The ca. 1680 Ma felsic Tunkilla  
775 Suite in the Gawler Craton (Fig. 1c) (Payne et al., 2010) which exhibits a large isotopic variation  
776 ( $\epsilon\text{Nd}_{(1680)}$  -6.3 to +2.6) is one possible exception. Erosion ca. 1595 Ma of a crustal pile that included  
777 this ca. 1680 Ma felsic material as well as more refractory Archaean to Palaeoproterozoic precursors  
778 is considered to be consistent with the isotopic fingerprint of the Radium Creek Group.

779 The ca. 1600-1540 Ma Musgravian Gneiss in the Musgrave Block, is characterised by juvenile Nd and  
780 Hf isotopic compositions (Gum and Belousova, 2006; Kirkland et al., 2012; Wade et al., 2006) that  
781 are too juvenile to be considered as viable correlatives with the ca. 1595 Ma Radium Creek Group.

782 Therefore, it is unlikely that the Radium Creek Group represents derivation from a proposed ca.  
783 1600-1540 Ma magmatic arc in the Musgrave Block.

784 Correlation of the felsic magmatic-derived ca. 1850 Ma zircon grains in the Radium Creek Group is  
785 permissible with Hf datasets from the Olympic (Belousova et al., 2009) and Spencer domains  
786 (Szpunar et al., 2011) (Fig. 11a) of the Gawler Craton (Fig. 1c). These grains reflect the emplacement  
787 of the felsic Donington Suite (Fig. 1c) in the Gawler Craton (Drexel et al., 1995) which has  $\epsilon \text{Hf}_{(1850)}$   
788 value range between -4 and +5 (Reid et al., 2008; Szpunar et al. 2011). These data indicate both  
789 reworking of the ca. 2500 Ma material as well as some juvenile input ca. 1850 Ma.

790 These data are similar to the ca. 1850 Ma Mount Isa Inlier Hf dataset (Fig. 12c) (Griffin et al. 2006)  
791 which corresponds to the emplacement of the ca. 1856 Ma Kalkadoon Batholith and co-magmatic  
792 Leichardt Volcanics (Page, 1983), and reflects remelting of Late Archaean material ca. 2500 Ma. The  
793 ca. 1850 Ma event in the Mount Isa Inlier does, however, comprise a far greater degree of mafic  
794 rocks with very positive  $\epsilon \text{Hf}_{(1850)}$  and are isotopically similar to the depleted mantle at ca. 1850 Ma.  
795 No such mafic (Fig. 9) and primitive isotopic signature (Fig. 8a,d) was detected for zircons from the  
796 Radium Creek Group.

797 The Neoarchaeon to Earliest Palaeoproterozoic zircon grains in the Radium Creek Group return a  
798 broad range of  $\epsilon \text{Hf}_{(t)}$  values (-5.15 to +4.12), consistent with derivation from a complex Archaean  
799 source terrane that comprises both reworked and juvenile components. Whilst this is largely similar  
800 to the Archaean Mount Isa Inlier (Fig. 12c; Griffin et al. 2006) and Gawler datasets (Belousova et al.,  
801 2009; Howard et al., 2011a;2011b), both the more evolved  $\epsilon \text{Hf}_{(t)}$  values and > ca. 2600 Ma U-Pb  
802 populations evident in sample ARK661 (Elburg et al., 2012), are more consistent with derivation from  
803 average Archaean Gawler Craton crust (Fig. 11a-b). This crust includes the Meso-Neoarchaeon  
804 Middleback Group (Szpunar et al., 2011) preserved in Spencer and Cleve domains, granite gneisses  
805 (Fraser et al., 2010), and the Sleaford and Mulgathing complexes preserved in the Coultas and  
806 Christie domains of the Gawler Craton (Fig. 1c) (Cowley and Fanning, 1992; Fanning, 1997; Schaefer,  
807 1998; Swain et al., 2005a).

808 Collectively the detrital zircon isotopic pattern of the Radium Creek Group requires a complex source  
809 terrane. This source must include a significant felsic Early Mesoproterozoic portion as well as  
810 Neoarchaeon to Palaeoproterozoic material that has undergone phases of Late Archaean to Early  
811 Mesoproterozoic re-working. This older material must itself have incorporated some juvenile  
812 components.

813 We consider the Gawler Craton to be the most plausible source for this composite signature of the  
814 ca. 1595 Ma Radium Creek Group. In this scenario, the Mount Painter Province is likely to be  
815 proximal to, and receiving material from, the eastern and central Gawler Craton at ca. 1595 Ma. The  
816 most probable source would be sub-aerial exposures of voluminous ca. 1595 Ma felsic material  
817 associated with the Gawler Range Volcanics felsic large igneous province (FLIP) (Pankhurst et al.,  
818 2013), particularly zircon grains derived from the Lower Gawler Range Volcanics.

#### 819 **4.6 Proterozoic tectonic implications**

820 Korsch et al. (2010) interpreted a distinctive seismic basement (termed the Warrakimbo Seismic  
821 Package) below the Mount Painter Province. We suggest that this basement is the eastern extension  
822 of the Gawler Craton and that the palaeo-Paralana Fault represents the eastern extent of the Gawler  
823 Craton. The palaeo-Paralana Fault is interpreted a moderately south-east-dipping, crustal-scale fault  
824 that separates the Warrakimbo and Yarramba seismic packages and has been interpreted as a major  
825 crustal boundary (Korsch et al. 2010).

826 Since we now consider the Freeling Heights Quartzite and the Mount Adams Quartzite to be lateral  
827 equivalents and stitch the Paralana Fault, the age of the tectonic boundary (possibly a suture)  
828 between the Warrakimbo and Yarramba seismic packages must pre-date ca. 1595 Ma. Further, the  
829 isotopic and geochemical similarities between the Upper Gawler Range Volcanics and the Benagerie  
830 Volcanic Suite (Wade et al., 2012) suggests the lower crust in the footwall of the palaeo-Paralana  
831 Fault may represent the same crustal sources (e.g. Pankhurst et al., 2013) of magmatism as the  
832 central Gawler Craton. The correlation of the upper Gawler Range Volcanics with the Benagerie  
833 Volcanic Suite in the Curnamona Province (Wade et al., 2012) stitches the Gawler Craton and  
834 Curnamona Province together at ca. 1587 Ma.

835 An extensional event ca. 1595 Ma as suggested by Stewart and Betts (2010) is consistent with this  
836 scenario and supported by the interpretation by Korsch et al. (2010). In this scenario the Radium  
837 Creek Group was deposited within an extensional basin setting following the Olarian-Wartakan  
838 orogenic system (Page et al., 2005; Hand et al., 2007; Stewart and Betts, 2010). This tectonic system  
839 could be quite far-reaching, and include the Mount Woods Inlier and northern Gawler Craton (Cutts  
840 et al., 2011; Forbes et al., 2012) across southern Proterozoic Australia. This extensional phase was  
841 followed by renewed crustal shortening and inversion of the Radium Creek Metamorphics (Armit et  
842 al., 2012), and may have affected the northern Gawler Craton (Kararan Orogeny: Hand et al., 2007),  
843 southern Curnamona Province (Rutherford et al., 2007), and the Mount Isa Inlier (e.g., Betts et al.,  
844 2006). Repeated rapid switching from extension to shortening at convergent plate margins is  
845 common during transient episodes of flat subduction (Gutscher et al., 2002) or when subduction roll-

846 back is interrupted by accretion of buoyant material such as an ocean plateau (Rosenbaum et al.,  
847 2005; Mason et al., 2010), plume-head (Murphy et al., 1998; Betts et al., 2009; 2012), arc terrane  
848 (Boutelier et al., 2003) or continental micro-continent (Moresi et al., in review), which are all  
849 characterised by local trench advance and shortening in the overriding plate. We propose that  
850 during the ca. 1595-1555 Ma interval, the Mount Painter Inlier was located in the overriding plate of  
851 one or more subduction zones and was subjected to tectonic mode switches caused by disruption of  
852 a convergent margin.

853 The palaeogeographic reconstructions of Betts & Giles (2006) (Fig. 2a); Betts et al. (2002; 2009),  
854 Cawood and Korsch et al. (2008) and Wade et al. (2006) (Fig. 2b) are consistent the Mount Painter  
855 Inlier being positioned proximal to one or more plate margins at ca. 1595 Ma. The configuration of  
856 Wade et al. (2006) does not have the Gawler Craton and the Curnamona Province co-located  
857 between ca. 1600-1580 Ma (Fig. 2b). The model of Wade et al. (2006) proposes that the Gawler  
858 Craton was positioned in the overriding plate of the south-dipping subduction zone prior to collision  
859 with the North Australian Craton at ca. 1590 Ma (Fig. 2b). In our reconstruction, the Curnamona  
860 Province is also required to be co-located with the Gawler Craton and therefore must have evolved  
861 in a back-arc setting on the overriding plate of a south dipping subduction zone and separated from  
862 the Mount Isa Inlier before ca. 1580 Ma (Fig. 2b). In this model, the Radium Creek Group would  
863 have been deposited in a back-arc setting and subsequent shortening resulted from collision  
864 between North and South Australian cratons at ca. 1560 Ma. However, separation between the  
865 North and South Australian cratons seems unlikely because of the well-established correlation of the  
866 ca.1720 to 1640 Ma basin systems between the Curnamona Province and North Australian Craton  
867 (Giles et al., 2002; Page et al., 2005; Conor and Priess, 2008; Gibson et al., 2008). We therefore  
868 consider a south-dipping subduction zone along the northern edge of the South Australian Craton  
869 highly unlikely at the beginning of the Mesoproterozoic.

870 The palaeogeographic reconstructions of Betts et al. (2002) and Betts and Giles (2006) consider that  
871 North and South Australian cratons to be contiguous at ca. 1600 Ma. The South Australian Craton  
872 was positioned between a long-lived accretionary convergent margin along the southern edge of the  
873 Australian continent (Betts et al., 2011), and a convergent margin along the eastern edge of the  
874 continent (Betts et al., 2002). Both these subduction zones are interpreted to dip towards the  
875 interior of the Australian continent (Betts et al., 2009). Superimposed on this complex tectonic  
876 setting is a major plume-related magmatic event (Betts et al., 2007; 2009). Tectonic interpretation of  
877 the evolution of the North Australian and South Australian cratons suggest that protracted episodes  
878 of high temperature metamorphism and continental basin systems formed in a back-arc setting

879 (Giles et al., 2002; Cutts et al., 2013), which were interrupted by transient accretion events (Betts et  
880 al., 2011) at the plate margin. Betts et al., (2009) proposed that the Olarian-Wartaken orogenic  
881 event was driven by the accretion of a plume-head with the Australian continent, which was  
882 followed by an episode of crustal extension after the transfer of the plume to the overriding plate  
883 (see Betts et al., 2013), producing a voluminous FLIP (Pankhurst et al., 2013) and a hotspot track  
884 defined by dominantly A-type magmatism after ca. 1600 Ma (Betts et al., 2007). We suggest that  
885 the deposition of the Radium Creek Group occurred in an extensional basin sourced from the FLIP  
886 preserved on the Gawler Craton (Fig. 13a). The Radium Creek Group were buried to mid crustal  
887 levels and then exhumed to the upper crust between ca. 1592 and ca. 1585 Ma requiring rapid  
888 switches to crustal shortening (Fig. 13b) to renewed extension (Armit et al., 2012). This was followed  
889 by renewed crustal shortening at ca. 1570-1555 Ma (Rutherford et al., 2007; Armit et al., 2012) (Fig.  
890 13c). We interpret the tectonic switching is driven by perturbations in the convergent margin. We  
891 are unable to assess the relative role of these convergent margins but may speculate that the earlier  
892 shortening events (ca. 1585 Ma) is related to accretion along the southern margin of the continent  
893 (Fig.13a-b), whereas ca. 1570-1555 Ma shortening is related to subduction along the eastern margin  
894 of the continent (Fig. 13c).

## 895 **5 Conclusions**

896 The Radium Creek Group consists of a single stratigraphic package deposited in the Early  
897 Mesoproterozoic with a maximum deposition  $^{207}\text{Pb}/^{206}\text{Pb}$  age of  $1595.5 \pm 3.7$  Ma ( $n=41$ ). The isotopic  
898 fingerprint of the Radium Creek Group requires a source with diverse but predominantly felsic  
899 character and evolved isotopic sources reflecting poly-phased crustal reworking from the Archaean  
900 to the Early Mesoproterozoic. Detrital zircon patterns in the Radium Creek Group that contains  
901 peaks at ca. 2500 Ma, ca. 1850 Ma, 1710-1780 Ma and 1660-1680 Ma. These ages are consistent  
902 with derivation from the Gawler Craton as opposed to other tectonic elements of eastern  
903 Proterozoic Australia, suggesting the Curnamona Province and Gawler Craton were co-located at ca.  
904 1595 Ma. The implication of this interpretation is that the North and South Australian cratons were  
905 contiguous at ca. 1595 Ma placing the Mount Painter Inlier at the nexus of two convergent margins  
906 characterised by subduction zones that dip towards the continent interior. Perturbations in the  
907 dynamics of these convergent margins resulted in rapid tectonic switches following deposition of the  
908 Radium Creek Group. Our data provides a critical constraint for palaeogeographic reconstruction for  
909 eastern Australia at the Palaeo- to Mesoproterozoic transition.

910

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912

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## 921 **Figure Captions**

922

923 Fig. 1: a) Map of Australia showing the geography-based nomenclature after Myer et al. (1996) in  
924 which the continent is divided into three major cratonic units, called the North, West and South  
925 Australian cratons draped over a composite of the bouguer gravity and first vertical derivative of the  
926 total magnetic intensity (TMI) map of Australia (geophysical data provided by Geoscience Australia);  
927 b) Map highlighting the location of the Mount Painter Block and other eastern Australian Proterozoic  
928 terranes in relation to the major geological provinces of Australia. These are draped across a  
929 composite total magnetic intensity (TMI) anomaly and first vertical derivative of the TMI map of  
930 Australia. This magnetic image was produced using a two kilometre grid spacing and by applying a  
931 low pass filter (upward continued six kilometres), which highlights the longer wavelengths/major  
932 structural elements of eastern Australia. Data provided by Geoscience Australia; c). Map showing the  
933 position of the Mount Painter Province (grey box) in respect to the major domains and Archaean to  
934 Mesoproterozoic geology of the Curnamona Province after Conor and Preiss (2008) and the Gawler  
935 Craton modified after Fairclough et al. (2003) and Hand et al. (2007).

936 Fig 2: a) Palaeogeographical reconfiguration model after Giles et al. (2004); Betts and Giles (2006)  
937 supporting a shared history for the South Australian Craton and the North Australian Craton  
938 between ca. 1800 and 1550 Ma. This configuration aligns contemporaneous orogenic belts across  
939 the Gawler Craton, Arunta Inlier, Mount Isa Inlier and the Curnamona Province.; b)  
940 Palaeogeographical reconfiguration model after Wade et al. (2006) in which the Gawler Craton and  
941 Curnamona Province are separated by a south-dipping subduction zone between ca.1600-1580 Ma  
942 with the Gawler Craton positioned in the overriding plate.

943 Fig. 3: Map of the Mount Painter Inlier showing sample locations and regional geology after Armit et  
944 al. (2012).

945 Fig. 4: a) Photograph of the steeply dipping, foliated psammopelites of the Brindana Schist unit at  
946 the base of Radium Creek Group, geo-pick shown for scale (sample Z3 363800E 6675681N); b)  
947 Photo-micrograph of a thin section of sample Z3 from the Brindana Schist in cross-polarised light, cut  
948 normal to the  $S_3$  foliation. This view demonstrates overprinting, spaced foliations defined by  
949 muscovite  $\pm$  biotite fabrics (sub-horizontal in photo-micrograph) and recrystallised polygonal quartz  
950 aggregate (microlithons); c) Photograph of the intensely crenulated, micaceous quartzite outcrop of  
951 the Freeling Heights Quartzite (sample F 357632E 6673138N); d) Photo-micrograph of a thin section  
952 of the Freeling Heights Quartzite in cross-polarised light. The section, taken normal to the  $S_3$   
953 foliation, highlights a spaced schistosity defined by muscovite with elongate relic quartz grains which  
954 display undulose extinction. A discrete crenulation cleavage overprints the existing schistosity; e)  
955 Photograph of quartzite unit of the Freeling Heights Quartzite (sample 123 355996E, 6672099N).

956 Cross-beds defined by heavy minerals and distinct compositional layering (compare with bottom  
 957 right of picture) record reverse grading. This indicates that younging is upwards and towards the  
 958 west (head of the geo-pick is orientated E-W); f) Photo-micrograph of sample 123 in cross-polarised  
 959 light. The section was cut normal to the  $S_3$  foliation and highlights two spaced and overprinting  
 960 foliations defined by biotite  $\pm$  muscovite and polygonal quartz-rich microlithons; g) Photograph of  
 961 the fine-grained pinky-grey micaceous quartzite outcrop of the Mount Adams Quartzite (Sample 36;  
 962 357161E, 6668472N). Cross beds defined by heavy minerals indicate upward younging; h) Photo-  
 963 micrograph of sample 36 in cross-polarised light shows fine grained muscovite, sercite and quartz-  
 964 rich assemblage. A sub-horizontal spaced foliation, defined by fine-grained micaceous material,  
 965 overprints an earlier mica fabric with polygonal undulose quartz and biotite microlithons; i)  
 966 Photograph of a hand specimen from the Pondanna member of the upper Gawler Range Volcanics  
 967 (573593E, 6405524N) showing porphyritic texture with phenocrysts of quartz and feldspar within a  
 968 dark, aphanitic groundmass; j) Photo-micrograph of Sample YD23a from the Pondanna member of  
 969 the upper Gawler Range Volcanics (573593E, 6405524N), section shows phenocrysts of k-feldspar,  
 970 quartz, and pyroxene within a fine grained matrix .

971 Fig. 5: Cathodoluminescence and back scatter electron images (a-d & e-j respectively of representative  
 972 zircon grains from each sample analysed in this study. The region ablated during analysis is  
 973 indicated; a) Z1-29a,b zircon grains from sample Z3 (Brindana Schist). Z1-29a grain has a U-Pb age  
 974  $1659 \pm 15$  Ma and an  $\epsilon_{Hf}$  value of +5.80, Z1-29b grain has a U-Pb age of  $1604 \pm 16$  Ma and a  $\epsilon_{Hf}$  value  
 975 of -6.1; b) Z3-24 zircon grain from sample Z3 (Brindana Schist). This grain has a U-Pb age of  $2369 \pm$   
 976  $28$  Ma and an  $\epsilon_{Hf}$  value of -4.89; c) F6 zircon grain from sample F (Freeling Heights Quartzite). This  
 977 grain has a U-Pb age of  $1670 \pm 10$  Ma and an  $\epsilon_{Hf}$  value of +0.01; d) F9 zircon grain from sample F  
 978 (Freeling Heights Quartzite). This grain has a U-Pb age of  $2539 \pm 28$  Ma and an  $\epsilon_{Hf}$  value of +1.29; e)  
 979 36-13 zircon grain from sample 36 (Mount Adams Quartzite). This grain has a U-Pb age of  $1596 \pm 8$   
 980 Ma and an  $\epsilon_{Hf}$  value of -1.79; f) Back scatter electron image of 36-10 zircon grain from sample 36  
 981 (Mount Adams Quartzite). This grain has a U-Pb age of  $1678 \pm 29$  Ma and an  $\epsilon_{Hf}$  value of -1.64; g)  
 982 123-17 zircon grain from sample 123 (Freeling Heights Quartzite). This grain has a U-Pb age of  $1589 \pm$   
 983  $9$  Ma; h) 123-1 zircon grain from sample 123 (Freeling Heights Quartzite). This grain has a U-Pb age  
 984 of  $1712 \pm 8$  Ma; i) YD23a-7 zircon grain from sample YD23a (uGRV). This grain has a U-Pb age of  
 985  $1596.2 \pm 36$  Ma and an  $\epsilon_{Hf}$  value of -2.74; j) YD23a-27 zircon grain from sample YD23a (uGRV). This  
 986 grain has a U-Pb age of  $1597.6 \pm 47$  Ma and a  $\epsilon_{Hf}$  value of -4.5.

987 Fig. 6: a) Probability plot of detrital zircons analysed from sample Z3. Inset: weighted mean  
 988  $^{207}\text{Pb}/^{206}\text{Pb}$  ( $2\sigma$ ) age plot for the youngest population in this sample, interpreted as the maximum  
 989 depositional age.; b) Concordia plot for zircons analysed from sample Z3 ;c) Probability plot of  
 990 detrital zircons analysed from sample F. Inset: weighted mean  $^{207}\text{Pb}/^{206}\text{Pb}$  ( $2\sigma$ ) age plot for the  
 991 maximum depositional age of this sample; c) Zircon grains from sample F plotted on a U-Pb  
 992 concordia plot; d) Concordia plot for zircons analysed from sample F; e) Detrital zircon probability  
 993 plot from sample 123. Inset: weighted mean age  $^{207}\text{Pb}/^{206}\text{Pb}$  ages ( $2\sigma$ ) for the maximum depositional  
 994 age ; f) Concordia diagram for zircons analysed from sample 123; g) Probability plots for zircon  
 995 analysed from sample 36. Inset: weighted mean  $^{207}\text{Pb}/^{206}\text{Pb}$  ages ( $2\sigma$ ) for the maximum depositional  
 996 age for this sample; h) U-Pb concordia plot for zircon analysed from sample 36.

997 Fig. 7: Weighted mean  $^{207}\text{Pb}/^{206}\text{Pb}$  ages plot for sample YD23a showing the dominant population  
 998 and older inherited grains. Inset: Tera-Wasserburg concordia plot shows the concordant (<10%  
 999 discordant) analyses, as well as all data >10% discordant from this sample. Data error ellipses and  
 1000 error bars used are  $1\sigma$ .

1001 Fig. 8: a) Plot of  $\varepsilon \text{Hf}_{(t)}$  versus  $^{207}\text{Pb}/^{206}\text{Pb}$  ages for the Radium Creek Group samples; b) Plot of  $T_{\text{DM}}^{\text{c}}$   
1002 versus  $^{207}\text{Pb}/^{206}\text{Pb}$  ages for the Radium Creek Group samples; c) Plot of  $\varepsilon \text{Hf}_{(t)}$  versus  $^{207}\text{Pb}/^{206}\text{Pb}$  ages  
1003 for the Radium Creek Group samples including values for ARK661 sample from Elburg et al. (2012)  
1004 compared with the values for the upper Gawler Range Volcanics, uGRV from the Gawler Craton  
1005 (sample YD23a), and the Frome Granite of the Bimbowrie Suite (sample FG12) and Benagerie  
1006 Volcanic Suite (sample BV) from the Curnamona Province (see Fig. 1c-d for sample locations). Insert  
1007 shows a plot of  $T_{\text{DM}}^{\text{c}}$  versus  $^{207}\text{Pb}/^{206}\text{Pb}$  ages for these samples; d) Field for the Radium Creek Group  
1008  $\varepsilon \text{Hf}_{(t)}$  values plotted as gridded density and data points for comparison. Density grid constructed  
1009 using cell size of 20 Myr in the X direction and 0.5  $\varepsilon \text{Hf}$  units in the Y direction, a threshold level of  
1010 0.05 and a smoothing level of 3.

1011 Fig. 9: Comparison of zircon crystallisation rock type, modelled from in-situ trace chemistry after  
1012 Belousova et al. (2002) to determine the source rock type of zircon grains across the Paralana Fault.  
1013 Sample F (357632E 6673138N) is from the Freeling Heights Quartzite to the west (Hangingwall) of  
1014 the Paralana Fault. Sample 36 (357161E, 6668472N) is from the Mount Adams Quartzite to the east  
1015 (Footwall) of the Paralana Fault. The modelled source rock type is predominantly felsic and  
1016 indistinguishable across the Paralana Fault.

1017 Fig. 10: Stratigraphic and structural framework of the Mount Painter Inlier using data from this study  
1018 and Armit et al. (2012). Proterozoic magmatic ages determined using U-Pb geochronology by LA-  
1019 ICPMS and SHRIMP where available. Mount Neill Granite and porphyry age from Teale (1987,  
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1037 Collins and Williams, 1995; Maidment et al., 2005; Scrimgeour et al., 2005). Stratigraphy after Armit  
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1039

1040 Fig. 11: a) Plot of  $\varepsilon \text{Hf}_{(t)}$  versus  $^{207}\text{Pb}/^{206}\text{Pb}$  ages for Archaean to Mesoproterozoic zircon populations  
1041 for the major domains of the Gawler Craton from Belousova et al. (2009); Howard et al.  
1042 (2009;2010;2011a;2011b); Szpunar et al. (2011), compared with the samples from the Radium Creek  
1043 Group (this study); b) Field for the Gawler Craton  $\varepsilon \text{Hf}_{(t)}$  values from Belousova et al. (2009); Howard  
1044 et al. (2009;2010;2011a;b); Szpunar et al. (2011) plotted as gridded density and data points for  
1045 comparison with the samples from the Radium Creek Group plotted as points. Density grid  
1046 constructed using cell size of 20 Myr in the X direction and 0.5  $\varepsilon \text{Hf}$  units in the Y direction, a  
1047 threshold level of 0.05 and a smoothing level of 3.

1048 Fig. 12: a) Plot of  $\varepsilon \text{Hf}_{(t)}$  versus  $^{207}\text{Pb}/^{206}\text{Pb}$  ages for Archaean to Mesoproterozoic zircon populations  
1049 from the Arunta Block (Hollis et al. 2010) displayed as a gridded density field compared with the  
1050 samples from the Radium Creek Group shown as points; b) Plot of  $\varepsilon \text{Hf}_{(t)}$  versus  $^{207}\text{Pb}/^{206}\text{Pb}$  ages for  
1051 Archaean to Mesoproterozoic zircon populations from the Broken Hill Block of the Curnamona  
1052 Province (Condie et al. 2005) displayed as a gridded density field, compared with the samples from  
1053 the Radium Creek Group shown as points; c) Plot of  $\varepsilon \text{Hf}_{(t)}$  versus  $^{207}\text{Pb}/^{206}\text{Pb}$  ages for Archaean to  
1054 Mesoproterozoic zircon populations from the Broken Hill Block of the Mount Isa Inlier (Griffin et al.  
1055 2006) displayed as a gridded density field compared with the samples from the Radium Creek Group  
1056 shown as points. All U-Pb dates shown as  $^{207}\text{Pb}/^{206}\text{Pb}$  ages, Hf isotope values recalculated using a  
1057 decay constant of  $1.865\text{E}10^{-11}/\text{yr}$ . Density grids for the Radium Creek Group, Gawler Craton,  
1058 Curnamona Province and Mount Isa Inlier are constructed using cell size of 20 Myrs in the X direction  
1059 and 0.5  $\varepsilon \text{Hf}$  units in the Y direction, a threshold level of 0.05 and a smoothing level of 3.

1060  
1061 Fig 13: a) Palaeogeographical reconstruction of eastern Proterozoic Australia at ca. 1595 Ma adapted  
1062 after Giles et al. (2004); Betts and Giles (2006); Betts et al. (2006;2007;2009). In this model the  
1063 Radium Creek Group are deposited in an extensional back-arc basin and sourced from the felsic  
1064 large igneous province (FLIP) preserved on the Gawler Craton; b) Rapid tectonic switching to  
1065 shortening ca. 1585 Ma and back to extension is driven by perturbations in the convergent margins  
1066 along the southern margin of Australia; c) Renewed crustal shortening at ca. 1555 Ma is related to  
1067 subduction along the eastern margin of the continent.

1068  
1069 Table 1: Lu-Hf values for standards run to determine instrumentation precision and accuracy.

1070 Table 2: U-Pb values for standards run during the study acquisition period and longer-term averages  
1071 indicating the level of reproducibility and instrument stability obtained.

1072 Table 3: Summary of the U-Pb dating and Hf isotope analysis.

1073 Table 4: Zircon crystallisation rock type, modelled rock type from in-situ trace element chemistry  
1074 after Belousova et al. (2002).

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1474

1 **Provenance of the Early Mesoproterozoic Radium Creek Group in the**  
2 **Northern Mount Painter Inlier: Correlating isotopic signatures to**  
3 **inform tectonic reconstructions.**

4  
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11

12 New in-situ zircon LA-ICPMS geochronologic and Hf-isotope data from the  
13 Radium Creek Group within the Mount Painter Inlier provide important  
14 temporal constraints on the Early Mesoproterozoic palaeogeography of  
15 eastern Proterozoic Australia. The entire Radium Creek Group was deposited  
16 in a single basin forming phase, and has a maximum depositional age of  
17  $1595 \pm 3.7$  Ma. Detrital zircon from these metasedimentary rocks have U-Pb  
18 age populations at ca. 1595 Ma, ~~1650-1660~~ 1680 Ma, 1710-~~1760~~ 1780 Ma, ca.  
19 1850 Ma and ca. 2500 Ma. These grains are characterised by isotopically  
20 diverse and evolved sources, and have crystallised within predominantly  
21 felsic igneous host-rocks. The relative age spectra and isotopic character has  
22 more similarity with the Gawler Craton than the Arunta Block, Curnamona  
23 Province or the Mount Isa Inlier. These observations suggest that the Mount  
24 Painter Province was adjacent to the Gawler Craton in the Early  
25 Mesoproterozoic, ~~and can therefore be interpreted as a marginal terrane of~~  
26 ~~the Gawler Craton.~~ Our data supports a coherent South Australian Craton  
27 at ca. 1595 Ma and a contiguous continental mass that included the North  
28 and South Australian cratons. The Mount Painter Inlier occupied a complex  
29 plate tectonic setting in the overriding plate of two convergent margins.

30 *Keywords: Radium Creek Group, [Mount Painter Inlier](#), U-Pb maximum depositional ages, Hf isotopes,*  
31 *isotopic fingerprinting, ~~Gawler Craton~~[Palaeogeographical reconstructions](#)*

32 **1. Introduction**

33 ~~Geochronology coupled with isotopic fingerprinting of ancient rock packages is a powerful tool for~~  
34 ~~constraining reconstructions of Proterozoic terranes. This is because information can be resolved in~~  
35 ~~greater detail than other methods traditionally used for palaeogeographic reconstructions (e.g.~~  
36 ~~Cawood et al., 1999; Halilovic et al., 2004; Nelson, 2001). This allows us to reconstruct links between~~

37 ~~cratonic elements with greater confidence, which improves our global reconstructions of ancient~~  
38 ~~supercontinents.~~

39 Tectonic reconstruction models of Proterozoic Australia have been enthusiastically debated in the  
40 literature (c.f. Betts and Giles, 2006; Gibson et al., 2008; Giles et al., 2004; Korsch et al., 2009; Swain  
41 et al., 2008; Wade et al., 2006). This is because understanding the Proterozoic record of Australia  
42 underpins ~~our~~the knowledge of how this continent has evolved ~~for the majority of its existence, and,~~  
43 ~~which~~ informs ~~our~~the view of global tectonics through time. ~~Central to most of these various~~  
44 ~~Proterozoic Australia models is the important link between the South Australian Craton and the~~  
45 ~~Northern Australian Craton, particularly at the nexus between the Palaeo- and Mesoproterozoic.~~

46 ~~Current geologic/tectonic understanding of Proterozoic Australia can be considered following the~~  
47 ~~Palaeo-geography-based nomenclature of Myer et al. (1996) in which the continent is divided into~~  
48 ~~three major cratonic units, called the North, West and South Australian cratons (Fig. 1a). The South~~  
49 ~~Australian Craton comprises the Gawler Craton and the Curnamona Province (Fig.1b-c). The South~~  
50 ~~Australian Craton has a shared history with the North Australian Craton between ca. 1800 and 1550~~  
51 ~~Ma, suggesting that were contiguous during this interval. The South Australian Craton likely~~  
52 ~~separated from the North Australian Craton during the Mesoproterozoic to form a discrete cratonic~~  
53 ~~element (Giles et al., 2004). Consequently, the link between the South Australian Craton and the~~  
54 ~~Northern Australian Craton, particularly at the boundary between the Palaeoproterozoic and~~  
55 ~~Mesoproterozoic times is significant for determining the evolution of the Australian continent at this~~  
56 ~~time.~~

57 ~~Giles et al. eastern Australia suggests it(2004) interpreted a configuration of the Palaeoproterozoic~~  
58 ~~Australia where the South Australian Craton was positioned in a complex palaeogeographic~~  
59 ~~environment. It was rotated 52° counter clockwise around an Euler pole in the North Australian~~  
60 ~~Craton. This configuration aligned contemporaneous orogenic belts across the Gawler Craton,~~  
61 ~~Arunta Inlier, Mount Isa Inlier and the Curnamona Province (Fig. 2a). Using the configuration of Giles~~  
62 ~~et al. (2004), Betts and Giles (2006) suggested that between ca. 1700 and 1500 Ma, the contiguous~~  
63 ~~North and South Australia cratons (Fig 2a) were situated adjacent to, and were affected by, two~~  
64 ~~convergent margins (Betts and Giles, 2006), which had a. A plume-related continental hotspot track~~  
65 ~~was also superimposed upon them/these cratons (Betts et al., 2007; 2009). This complex geodynamic~~  
66 ~~setting has contributed to difficulties in reconciling the palaeogeography of Mesoproterozoic eastern~~  
67 ~~Australia. In this model, the southern margin of the Australian continent evolved in the overriding~~  
68 ~~plate of a north-dipping subduction, and the eastern margin of the continent sequentially evolved~~  
69 ~~from a passive margin, to a convergent margin with west-dipping subduction.~~

70 Wade et al. (2006) presented [an alternative](#) model in which the South Australian Craton collided  
71 with the North Australian Craton between ca. 1590 Ma and 1560 Ma, [\(Fig. 2b\)](#), chiefly supported by  
72 the identification of the ca. 1590 Ma continental-arc affinity rocks in the Musgrave Block, [of central](#)  
73 [Australia. In this model the continental arc rocks formed above a south-dipping subduction zone](#)  
74 [and the Gawler Craton evolved in a continental back-arc basin.](#) Gibson et al. (2008) proposed a  
75 model whereby eastern Proterozoic Australia evolved between ca. 1730 and 1640 Ma [within one by](#)  
76 [a series of](#) large intra-continental ~~back-arc~~ [systems](#) along the margins of the South  
77 Australian and North Australian cratons. This system was subsequently inverted [between](#) ca. 1640-  
78 [and 1600 Ma](#) during accretion of the Georgetown-Mojave Block. ~~A rotational model was presented~~  
79 ~~by These latter models consider~~ [Giles et al. \(2004\) whereby the Gawler Craton is rotated 52°](#)  
80 ~~clockwise, based on present-day distribution of Australia Palaeoproterozoic terranes to be~~  
81 [representative of their distribution at the alignment of orogenic belts correlated across the Gawler](#)  
82 [Craton, Arunta Inlier, Mount Isa Inlier and the Curnamona Province.](#) [time of tectonism.](#)

83 The key points of debate are:

- 84 1) the location and polarity of subduction systems,
- 85 2) the timing of major depositional and collisional events,
- 86 3) the interpretation of the spatial positions of the North Australian and South Australian  
87 Cratons through time with respect to one another (as a result of 1 and 2).

88 Increasing our knowledge of these ~~tectonic~~ [tectonic settings](#) will improve our understanding of the  
89 Palaeo-Mesoproterozoic evolution of Australia. Moreover, the knowledge will provide important  
90 constraints to larger-scale Nuna-Columbia supercontinent reconstructions.

91

92

### 93 1.2 A key terrane

94 The Mount Painter Inlier is situated within the northern, South Australian Craton margin (Fig. [41b-c](#)),  
95 which makes it an ideal location to explore the links between the North and South Australian  
96 cratons. In addition, this inlier helps us investigate the interface between the Gawler Craton and  
97 northern Curnamona Province, which is currently poorly understood.

98 Recently, Armit et al. (2012) suggested that the Early Mesoproterozoic deformation events recorded  
99 in the Mount Painter Inlier appear to be more similar to those observed in the northern Gawler  
100 Craton and Mount Isa Inlier, rather than the southern Gawler Craton and Curnamona Province.

101 According to that study, the Mount Painter region would be predicted to record an evolution more  
102 similar to that of the North Australian Craton rather than the South Australian Craton. If this is  
103 indeed the case, our interpretations of the relationships between these crustal elements, and the  
104 reconstructions to place the Mount Painter Inlier in its correct location through time, require a  
105 substantial re-appraisal.

106 ~~The implications of WeArmit et al.'s (2012) study highlights the need to better understand the~~  
107 ~~depositional and tectonic history of the Mount Painter Inlier. In this communication we have chosen~~  
108 ~~to~~ investigate the provenance and depositional environment of sediments/sedimentary rocks  
109 deposited at/in the nexus between the Palaeo- to Early Mesoproterozoic within the Mount Painter  
110 Inlier. ~~We then use these data to improve our interpretation of the tectonic setting for this inlier,~~  
111 which in turn as they may provide constraints on the palaeogeography of both the Mount Painter  
112 Province and ~~the~~ eastern Proterozoic Australia.

113 \*Insert Figure 1 here\*

### 114 1.3 Geological Background

#### 115 1.3.1 Crustal architecture

116 The Radium Creek Group (Preiss et al., 2010; a nomenclature revised from the Radium Creek  
117 Metamorphics) outcrops within the Mount Painter and Mount Babbage ~~Inliers/inliers~~, which are  
118 located at the northern tip of the Flinders Ranges in South Australia (see Fig. ~~4-1c~~). These Inliers have  
119 been ~~traditionally~~ interpreted as part of the Moolawatana Domain (Fig. 1c) that defines the north-  
120 western extent of the Curnamona Province (Conor and Preiss, 2008; Parker et al., 1993; Teale and  
121 Flint, 1993). ~~However, a recent deep Seismic reflection and magnetotelluric survey (08GA-C1) across~~  
122 ~~the area has been interpreted by Korsch et al., (2010), who demonstrate a major crustal-scale south-~~  
123 ~~dipping discontinuity between this Moolawatana Domain and the Curnamona Province to the south.~~  
124 ~~This interpretation suggests that a different basement (Gawler Craton) lies below the Mount Painter~~  
125 ~~Province. This basement is similar to that which underlies the western flanks of the Adelaide Fold~~  
126 ~~Belt (Preiss et al., 2010), and is distinct from that which underlies the rest of the Curnamona~~  
127 ~~Province.~~

128 A major crustal-scale south-east-dipping discontinuity between the Moolawatana Domain and the  
129 Curnamona Province has been interpreted from the deep seismic reflection and magnetotelluric  
130 survey (08GA-C1) by Korsch et al. (2010). This discontinuity has been interpreted as separating  
131 distinct basement blocks. The basement below the Moolawatana Domain on the north-western side  
132 of the discontinuity is termed the Warrakimbo Seismic Block by Korsch et al. (2010). This seismic  
133 block is characterised by markedly lower reflectivity than the Yarramba Seismic Province which is

134 | [interpreted to be basement to the Curnamona Province south-east of the major discontinuity](#)  
135 | [\(Korsch et al., 2010\).](#)

### 136 | 1.3.2 Stratigraphy

137 | Within the northern Mount Painter Inlier, the Radium Creek Group is ~~comprised~~[composed](#) of  
138 | micaceous psammites, psammopelites, pelitic schists, phyllites, feldspathic quartzites and  
139 | quartzofeldspathic gneisses. [\(Fig. 3\)](#). These rocks have yielded ~~Late Palaeoproterozoic to~~ Early  
140 | Mesoproterozoic (1600-1580 Ma) maximum depositional U-Pb zircon ages (Elburg et al., 2012;  
141 | Fanning et al., 2003; Fraser and Neumann, 2010). These ages appear to be significantly younger than  
142 | the [ca. 1720-1640 Ma](#) Willyama Supergroup [ca. 1720-1640 Ma](#) (Conor and Preiss, 2008) from the  
143 | southern part of the Curnamona Province and therefore previous correlations with the Radium  
144 | Creek Group are considered erroneous (e.g. Teale, 1993).

145 | The Radium Creek Group has undergone ~~multi-phased~~[polyphase](#) metamorphism (Elburg et al.,  
146 | 2003; McLaren et al., 2002) and poly-deformation in the Early Mesoproterozoic and Palaeozoic  
147 | (Armit et al., [2012](#)). ~~Due to this complexity, a number of different plausible geological frameworks~~  
148 | ~~have been suggested for the sedimentary stratigraphy of the Radium Creek Group. These include~~  
149 | ~~two phase depositional models (Fanning et al., 2003; Paul, 1998; Teale, 1993) and single phase~~  
150 | ~~models (Coats and Blissett, 1971; Elburg et al., 2001; [2012](#)).~~

151 | ~~The two phase models describe either, Palaeoproterozoic quartzofeldspathic sequences i.e. suites 4~~  
152 | ~~and 5 of Teale (1993) and separate Mesoproterozoic sequences i.e. suites 1 and 2 of Teale (1993).~~  
153 | ~~Alternatively, two Mesoproterozoic phases are separated by a deformation event (Paul et al., 1999;~~  
154 | ~~Fanning et al., 2003). The single phase model suggests that basal phyllites (Yagdlin Phyllite) are~~  
155 | ~~overlain by the Mount Adams Quartzite, Brindana Schist and Freeling Heights Quartzite (Coats and~~  
156 | ~~Blissett, 1971; Elburg et al., 2001).~~

### 157 | 1.3.3 Igneous suites

158 | ~~The metasediments~~[The metasedimentary rocks of the Mount Painter Province](#) are intruded by a  
159 | series of Early Mesoproterozoic igneous suites with A-type geochemical affinities (Elburg et al., 2012;  
160 | Kromkhun et al., 2013). ~~This includes the ca. 1585-1557 Ma~~ [The](#) Mount Neill Suite [was emplaced at](#)  
161 | [ca. 1585-1557 Ma](#) along the south-east margin of the inlier (Fig. ~~2) which~~[3](#)). [This suite](#) incorporates  
162 | the Box Bore and Mount Neill Granite (Elburg et al., 2012; Elburg et al., 2001; Fraser and Neumann,  
163 | 2010) ~~and the~~. [The](#) slightly younger ~~ca. 1560-1555 Ma~~ Moolawatana Suite [was emplaced between](#)  
164 | [ca. 1560 Ma and 1555 Ma](#) (Stewart and Foden, 2001) on the northern side of the Inlier. [\(Fig. 3\)](#). The  
165 | ca. 1552 Ma Hodgkinson Granodiorite (Fraser and Neumann, 2010) also intrudes the central part of  
166 | the Inlier and outcrops as a linear NE-SW belt. Numerous metabasic bodies intrude the Radium

167 Creek Group and are considered to be late Mesoproterozoic to Neoproterozoic in age (Wulser,  
168 2009). Minor pegmatite lenses throughout the Radium Creek Group in the northern Mount Painter  
169 Inlier are most likely syn- to post- the Cambro-Ordovician Delamerian Orogeny (Elburg et al., 2003).  
170 Within the central part of the inlier, the peraluminous British Empire Granite and metaluminous  
171 Paralana Granodiorite are interpreted to have been emplaced during the Palaeozoic ca. 460-440 Ma  
172 (Elburg et al., 2003; McLaren et al., 2006).

#### 173 1.3.4 Metasomatism

174 Lenses of peraluminous to hyperaluminous rock, composed of phlogopite-corrundum-kyanite  
175 bearing mineral assemblages are present within the Radium Creek Group in the Mount Adams area  
176 proximal to the Mount Neill Granite (Shafton, 2006). This lithology is correlated with the Corundum  
177 Creek Schist Member (Shafton, 2006) originally mapped as part of the Radium Creek Metamorphics  
178 (Coats and Blissett, 1971). Elburg et al. (2011) interpreted these bodies as metasomatised igneous  
179 rocks and most which likely reflect intense alteration of the Mount Neill Suite.

#### 180 1.3.5 Structure

181 The Inlier is bisected by the Paralana Fault Zone (Fig. 23) which also separates sequences of the  
182 Radium Creek Group. This fault system is a major crustal-scale feature and has a predominantly  
183 steep, northwest-dipping geometry as interpreted from the O8GA-C1 deep seismic reflection survey  
184 (Korsch and Kositcin, 2010). Field observations indicate that the fault zone is defined by a corridor of  
185 high strain, which record demonstrable reactivations since the Early Mesoproterozoic (Armit et al.,  
186 2012) through to the Cenozoic (Elburg et al., 2012; Teasdale, 1993).

#### 187 1.4 Approach of this study

188 [Geochronology coupled with isotopic fingerprinting of ancient rock packages is a powerful tool for](#)  
189 [constraining reconstructions of Proterozoic terranes \(e.g. Cawood et al. 1999; Halilovic et al. 2004;](#)  
190 [Nelson, 2001\). This allows us to reconstruct links between cratonic elements with greater](#)  
191 [confidence, which improves global reconstructions.](#)

192 This study aims to provide constraints on the timing and provenance of deposition of the Radium  
193 Creek Group. To achieve this we compare the isotopic and geochronological signatures of detrital  
194 zircon populations from these metasediments with that of neighbouring tectonic elements. Direct  
195 comparison of our new zircon age data with Precambrian terranes across eastern Australia can then  
196 be used to identify the most likely crustal element(s) those zircons, and thus sediments, are derived  
197 from.

198 In addition, the employment of trace element and Lu-Hf isotope system fingerprinting allows us to  
199 also compare the source (i.e. relative contemporary crust/mantle contribution) that different zircon

200 populations have crystallised from (Blichert-Toft and Albarede, 1997). These data have the potential  
201 to discriminate between terranes that have similar chronology, but different magmatic source  
202 chemistry and antiquity, allowing a further level of discrimination between potential sources of  
203 detritus. Our approach is to assess the U-Pb-Hf-trace element signature of [samples throughout](#) the  
204 Radium Creek Group ~~samples~~ and compare them to that of zircon populations from ~~other~~ potential  
205 source lithologies across a number of terranes, using both new data presented herein and published  
206 datasets from the Gawler Craton, Mount Isa Inlier, Curnamona Province and Arunta Block  
207 (Belousova et al., 2006b; Condie et al., 2005; Griffin et al., 2006; Hollis et al., 2010; Howard et al.,  
208 [2009; Howard et al., 2011a; Howard et al., 2011b; Howard et al., 2011c; Szpunar et al., 2011](#)).

209 Available whole rock Nd isotope datasets from across the region (Neumann, 2001; Schaefer, 1993;  
210 Wade et al., 2012) are also examined in order to further test observed temporal and spatial patterns  
211 with respect to relative inputs of juvenile material, [which](#) can provide insights into the provenance of  
212 the Radium Creek Group.

213 ~~\*Insert Figure 2 here\*~~

#### 214 1.5 Samples

215 Four samples from the Mount Painter Inlier were investigated ~~in extensive detail~~. Three of which  
216 (Z3, F and 123) are from the hanging wall (western side) of the Paralana Fault, ~~with the remainder~~  
217 [and one](#) from the eastern (foot-wall) side (see Fig. [2-3](#)). [Sample](#) Z3 is a sample of a fine-grained,  
218 mica rich, garnet + quartz psammopelitic horizon within the Brindana Schist (Fig. [3a,4a-b](#)). This  
219 horizon is located ~100 m to the west of the Paralana Fault and Mount Neill Granite Suite. [Sample](#) F  
220 is a medium-grained quartz + muscovite ± garnet layer within the Freeling Heights Quartzite ~6 km  
221 to the south-west of sample Z3 (Fig. [2,3e,4c-d](#)). 123 is a course grained quartz + muscovite layer of  
222 the Freeling Heights Quartzite (Fig. [3e,4e-f](#)). This sample location is ~2 kilometres south-west of  
223 sample F. 36 is a medium grained quartz + muscovite ± biotite ± garnet layer of the Mount Adams  
224 Quartzite (Fig. [3g,4g-h](#)), from the eastern side of both the Paralana Fault and the Mount Neill Granite  
225 Suite. ~~Thus good coverage of the Radium Creek Groups is achieved, incorporating both sides of the~~  
226 ~~major defining structure.~~

227 Additionally, we ~~included~~[studied](#) one sample from the Central Gawler Craton. [Sample](#) YD23A is a  
228 black, course-grained porphyritic (plagioclase + k-feldspar + iron oxide) sample (Fig. [3i,4i-j](#)) of the  
229 Pondanna member of the Upper Gawler Range Volcanics- (uGRV; Allen et al., 2003; Blissett et al.,  
230 1993). The uGRV is a major capping sequence of the Gawler Felsic Large Igneous Province (Allen et  
231 al. 2012), ~~comprised~~[and is composed](#) of widespread and homogeneous felsic lava (due to high  
232 magmatic temperature and halogen enrichment, promoting efficient mixing via low magmatic

233 viscosity: see Pankhurst et al. 2011a) that outcrops as monotonous sheets across the Central Gawler  
234 Craton. The emplacement of this voluminous felsic [large igneous province \(FLIP\)](#) was rapid  
235 (Pankhurst et al. ~~2011a~~[2011b](#)), and occurred at ca. 1592 ± 3 Ma (Fanning et al., 1988). As such, this  
236 sample represents both a snapshot of Gawler Craton evolution as well as the principle source of  
237 Gawler Craton-derived detritus, at the [apparent](#) time of Radium Creek Group deposition.

238 Finally, two samples are [taken](#) from drillholes ~150 ~~Kilometres~~[kilometres](#) to the south of the Mount  
239 Painter Inlier, within the Curnamona Province (Fig. [41b-c](#)). They have previously been dated using in-  
240 situ zircon U-Pb techniques by Jagodzinski & Fricke (2010). Sample R1707876 is ~~from~~[from](#) the Frome 12  
241 Granite, ~~Ninnerie Supersuite~~[Bimbowrie Suite](#), intersected in drillhole DDH Frome 12 (385176E,  
242 6503512N). Sample R1709059 is ~~of~~[from](#) rhyolite assigned to the Benagerie ~~Volcanics~~[Volcanic Suite](#),  
243 intersected in DDH Frome 13 (393612E, 66528251N). Both [of](#) these samples are ~~from~~[from](#) igneous  
244 rocks emplaced within the Curnamona Province [at](#) ca. 1594-1587 Ma (Jagodzinski and Fricke, 2010).  
245 They therefore contain information regarding the [Early Mesoproterozoic](#) evolution of ~~this tectonic~~  
246 ~~element at this time, which is key to understanding~~ the ~~Mount Painter Inlier~~[Curnamona Province](#), as  
247 well as representing a potential contemporary source for detritus contributing to the Radium Creek  
248 Group.

249 ~~\*Insert Figure 3 here\*~~

## 250 **2 Methods**

### 251 **2.1 Sampling for whole rock geochemistry and zircon extraction**

252 Several kilograms of representative material were collected from each site (see Fig. ~~2-3~~[4](#)).  
253 Weathered rinds and any obvious zones of alteration were discarded. These samples were then  
254 pulverised using a ceramic disc mill and sieved to collect the resulting fragments within an 18 to 250  
255 µm size range. Magnetite within this fraction was removed using a hand magnet. [Tetrabromoethane](#)  
256 ~~(TBE-; 2.96g/ml)~~ and [Di-iodomethane \(DIM-; 3.3g/ml\)](#) heavy liquids were then used to separate  
257 minerals with high specific gravity (including zircon) from the predominantly lighter medium. A  
258 further magnetic separation step followed using the heavy fraction. We used a Frantz magnetic  
259 separator set at 1.4 Amps, 15° forward and 25° side tilt.

### 260 **2.2 Zircon mounting, imaging and in-situ targeting**

261 Zircons were hand-picked from the non-magnetic fraction using a binocular microscope and  
262 suspended in an epoxy resin mount for grinding, polishing and carbon coating. The mounts were  
263 imaged using a JEOL JSM 6300 SEM at Ballarat University (both back scatter electron and cathode  
264 luminescence images) on the Brindana Schist sample (sample Z3), and a JEOL JSM-840A SEM (back  
265 scatter electron images only) at the Centre for Electron Microscopy, Monash University on the uGRV

266 sample (YD23a). A Cameca SX100 electron microprobe (back scatter electron and  
267 cathodoluminescence images) was used to image zircons from the Freeling Heights Quartzite  
268 (sample F, 123), Brindana Schist (sample Z3) and Mount Adams Quartzite (sample 36) at GEMOC,  
269 Macquarie University. These images (BSE and/or CL) were used to choose analysis spots for each  
270 grain. The most appropriate sites were those that best fit the criteria of adequate size, internal  
271 consistency and tractable petrographic context of crystal zonation domains.

272

## 273 2.3 Analytical methods

### 274 2.3.1 In-situ major and trace element chemistry

275 Electron microprobe (EMP) analysis for in-situ zircon major and trace-element ( $\text{HfO}_2$ ,  $\text{SiO}_2$ ,  $\text{ZrO}_2$ ,  
276  $\text{Y}_2\text{O}_3$ ) geochemistry was conducted on samples from the Freeling Heights Quartzite (samples F) and  
277 Mount Adams Quartzite (sample 36) using a Cameca SX100 Electron Microprobe fitted with 5  
278 wavelength dispersive spectrometers (WDS) and [Princeton Gamma-Tech \(PGT\)](#) energy dispersive  
279 system (EDS). The microprobe was operated at an accelerating voltage of 15 kV with a beam current  
280 of 20 nA, a 1-2  $\mu\text{m}$  beam diameter, and a dwell time of 60 seconds acquisition after 60 seconds  
281 background. The analyses were conducted at [the](#) same site within each zircon grain chosen for both  
282 the U-Th-Pb-trace and Hf-isotope analyses.

### 283 2.3.2 U-Th-Pb

284 In-situ zircon U-Th-Pb isotope analysis was conducted at Macquarie University using a HP 4500  
285 quadrupole ~~ICPMS~~[inductively coupled plasma mass spectrometer \(ICPMS\)](#) attached to a New Wave  
286 UV213 Laser system for samples Z3, F, 123 and 36. Analysis of zircon from sample YD23a was  
287 undertaken at Monash University by [laser ablation \(LA-\)](#) ICPMS attached to a Thermo X-series  
288 quadrupole coupled with a New Wave ~~213nm~~[213 nm](#), Nd: YAG laser. A laser spot size between 30-  
289 ~~40 $\mu\text{m}$~~ [40  \$\mu\text{m}\$](#)  was used depending on the size and morphological complexity of each zircon. Ablation  
290 sites were chosen to best represent populations from each of the distinct zircon morphologies that  
291 could be characterised from BSE and CL images of the zircon grains (see Fig. [45](#)). The lasers at both  
292 Macquarie University and Monash University were operated using a ~~5Hz~~[5 Hz](#) repetition rate with 11-  
293 ~~13mJcm<sup>-2</sup>~~[13 mJcm<sup>-2</sup>](#) laser energy at the sample with a 60-~~120s~~[120 s](#) acquisition period including  
294 ~~15ms~~[15 ms](#) dwell for  $\text{Pb}^{206}$ ,  $\text{U}^{238}$ , 10ms for  $\text{Pb}^{204}$ ,  $\text{Pb}^{208}$ ,  $\text{Th}^{232}$  and ~~30ms~~[30 ms](#) for  $\text{Pb}^{207}$ . The dwell  
295 times for sample YD23a (undertaken on the Monash University LA-ICPMS) differed slightly with a  
296 shorter ~~10ms~~[10 ms](#) dwell for  $\text{Pb}^{204}$  and ~~25ms~~[25 ms](#) for  $\text{Pb}^{206}$ ,  $\text{Pb}^{207}$ ,  $\text{Th}^{232}$  and  $\text{U}^{238}$ .

297

### 298 2.3.3 In-situ Lu-Hf

299 We targeted zircons for Hf isotope analysis that represented each distinct U-Pb age population  
300 within each sample. Hf isotopes were only measured from grains with U-Pb ages that were <10%  
301 discordant. The specific sites were chosen to be adjacent to the same pit and within the same  
302 internal domain, ablated for U-Pb isotopic analysis (identified by BSE and CL images: Fig. 45).

303 The in-situ zircon Lu-Hf isotope analytical technique used in this study follows that described by  
304 Griffin et al., (2004); Griffin et al., (2006); Griffin et al., (2002). Analysis was conducted at GEMOC,  
305 Macquarie University using a New Wave/Merchantek LUV213 (Nd: YAG) laser-ablation system  
306 attached to a Nu Plasma multicollector ICPMS via Ar/He gas delivery. The ICPMS was tuned using a 1  
307 ppm solution of the JMC475Hf standard spiked with 80 ppb Yb, which yielded a typical total Hf beam  
308 of  $10\text{-}14 \times 10^{-11} \text{ \AA}$  (Jackson et al., 2004).

309 The analyses in this study were carried out using a 40 to 55  $\mu\text{m}$  beam diameter with a 5Hz repetition  
310 rate and  $\sim 0.6 \text{ mJ/pulse}$  which produced a total Hf signal of  $1\text{-}6 \times 10^{-11} \text{ \AA}$ . Following 60 s of  
311 background measurement, 80-120 s of acquisition time per analysis produced  $\leq 50\mu\text{m}$  deep  
312 pits.

313 ~~\*Insert Table 1 here\*~~

314 During the analytical run, Mud Tank Zircon standard was analysed as an internal monitor (Table 1).  
315 These measurements yielded an average corrected  $^{176}\text{Hf}/^{177}\text{Hf}$  ratio of  $0.282527 \pm 0.000029$  (~~2 $\sigma$~~ ,  
316  $n=14$ , 2 $\sigma$ ), which is within the error of the long term average  $0.282532 \pm 0.000033$  (~~2 $\sigma$~~ - $n=984$ , 2 $\sigma$ )  
317 and  $0.282523 \pm 0.000043$  ( $n=2190$ ,  $2\sigma$ ) (Pearson, N.J. Pers comms, 2010). In addition, the 91500  
318 zircon standard was analysed, and yielded a corrected average  $^{176}\text{Hf}/^{177}\text{Hf}$  ratio of  $0.282322 \pm$   
319  $0.000059$  ( $n=4$ , ~~2- $\sigma$ 2 $\sigma$~~ ) which is within error of the long term average of  $0.282307 \pm 0.000058$  ( $n=632$ ,  
320  $2\sigma$ ) (from Pankhurst et al., 2013). In addition and where possible, multiple ablations of the same  
321 domain in our unknown samples (quasi repeat analyses) returned  $\epsilon \text{ Hf}$  values that were  
322 indistinguishable from the original analyses ( $1\sigma < 0.05 \epsilon \text{ Hf}$ ).

### 323 2.3.4 Whole-rock geochemistry

324 Splits ( $\sim 250 \text{ g}$ ) of ~~sample~~ Z3 and ~~sample~~ F were crushed using a hydraulic press and then  
325 further in an agate mill to produce a powder of each sample. A portion (~~15g~~ 15 g) of each powder  
326 was analysed for major elements using a Bruker-AXS S4 Pioneer XRF Spectrometer and processed  
327 through Bruker-AXS Spectra-plus ~~Software~~ software, at the Advanced Analytical Centre at James  
328 Cook University. This is the same method and laboratory that determined the whole rock data from  
329 sample Y23a (see Pankhurst et al. 2011a). Trace (including rare-earth element) data were acquired  
330 from high-pressure digestions using HF. This step was followed by ~~aan~~ HCl digestion at one

331 atmosphere before drying down and converting to nitric complexes using HNO<sub>3</sub>. These samples were  
332 then taken up in dilute HNO<sub>3</sub>, spiked with a Li, In and Bi internal standard before analysing the  
333 solutions using a quadrupole ICPMS at Monash University.

334

## 335 2.4 Data treatment

### 336 2.4.1 U-Th-Pb isotope ratios

337 U-Th-Pb isotopic ratios were calculated using GLITTER software (e.g. Van Archerbergh et al., 1999)  
338 and the U-Pb ages were calculated using Isoplot 4.15. The [procedure for](#) data reduction procedure  
339 [used](#) follows that of Griffin (2004) and Jackson et al. (2004) and in each case GEMOC GJ-1 zircon  
340 (TIMS normalisation values of Jackson et al. (2004) are: <sup>207</sup>Pb/<sup>206</sup>Pb 608.3 Ma, <sup>206</sup>Pb/<sup>238</sup>U 600.7 Ma  
341 and <sup>207</sup>Pb/<sup>235</sup>U 602.2 Ma) was used to correct for U-Pb fractionation. In addition, the 91500 zircon  
342 standard was analysed within each run as a monitor of the reproducibility and accuracy for both  
343 LAM-ICPMS instruments used (Table 2). A correction for <sup>204</sup>Pb was applied following the method  
344 described in Anderson (2002). This correction had a negligible effect on the majority of the  
345 [analysisanalyses](#). Absolute ages and their individual errors were calculated using Isoplot 4.15  
346 (Ludwig, 2008), and age populations were assessed with the unmix function (to unmix superimposed  
347 Gaussian distributions) as appropriate.

348 [\\*Insert Table 2 here\\*](#)

### 349 2.4.2 Zircon trace element data

350 A cameca  $\Phi$ p<sub>z</sub> correction procedure was applied to the EMP dataset to calculate oxide percentages  
351 from raw counts. The trace element concentration data (Y, Hf) were combined with U, Th, Lu, Yb  
352 concentration data acquired during the LAM-ICPMS analysis, and used to model potential magmatic  
353 source rock type (c.f. Belousova et al., 2002) for each grain, and by extension, on age populations.  
354 These data were collated for selected grains from [samplesample](#) F (n=16) and [sample](#) 36 (n=18)  
355 that satisfy our selection criteria: -grains were chosen to represent each of the U-Pb detrital age  
356 populations brackets, and were ~~checked that this~~ limited ~~the cut~~ to igneous crystals only, [by using](#)  
357 [geochemical data as a filter](#) (Th/U ratios of >0.5 normally indicate an igneous origin; Cowley and  
358 Fanning, 1992).

### 359 2.4.3 Lu-Hf isotope ratios

360 Measured masses 172, 175, 176, 177, 178, 179 and 180 were normalised to <sup>179</sup>Hf/<sup>177</sup>Hf = 0.7325  
361 using an exponential correction for mass bias. Interference of <sup>176</sup>Lu on <sup>176</sup>Hf was corrected using a  
362 <sup>176</sup>Lu/<sup>175</sup>Lu ratio = 0.02669 (Claoué-Long et al., 2008) and measuring the interference-free <sup>175</sup>Lu value  
363 to calculate <sup>176</sup>Lu/<sup>177</sup>Hf. Interference of <sup>176</sup>Yb on <sup>176</sup>Hf was corrected using a <sup>176</sup>Yb/<sup>172</sup>Yb ratio of  
364 0.5865 (see Griffin et al., 2000), determined by spiking the JMC475 Hf standard with Yb, and

365 measuring the interference-free  $^{172}\text{Yb}$  (Jackson et al., 2004). Repeated analysis of standard zircons  
366 (see 3.2.3 above) with a variety of  $^{176}\text{Lu}/^{177}\text{Hf}$  and  $^{176}\text{Yb}/^{177}\text{Hf}$  ratios (see Griffin et al., 2004)  
367 establishes the accuracy and precision of the Lu and Yb corrections.

368 The measured  $^{176}\text{Lu}/^{177}\text{Hf}$  ratios for each of the zircons analysed were used to calculate initial  
369  $^{176}\text{Hf}/^{177}\text{Hf}$  ratios. Numerous proposed decay constants exist for  $^{176}\text{Lu}$  (e.g. Bizzarro et al., 2003;  
370 Blichert-Toft et al., 1997; Scherer et al., 2001 ; Soderlund et al., 2004). We have used a value of  
371  $1.865\text{E}^{-11}/\text{yr}$  for all Hf isotope calculations (Scherer et al., 2001; Soderlund et al., 2004). Chondritic  
372 values of  $^{176}\text{Lu}/^{177}\text{Hf} = 0.282772$  and  $^{176}\text{Hf}/^{177}\text{Hf} = 0.0332$  (Blichert-Toft and Albarede, 1997) are used  
373 for calculating  $\varepsilon$  Hf and model ages.

374 The mean 2se precision of  $^{176}\text{Hf}/^{177}\text{Hf}$  ratios presented in this study is  $\pm 0.00002$  which equates to  
375  $\pm 0.7 \varepsilon$  Hf). The majority of the analyses returned a 2se uncertainty range between <1-5%  
376 contributing an uncertainty of between 0.05 and 0.25  $\varepsilon$  Hf. This uncertainty reflects the within-grain  
377 variation in Lu/Hf observed in zircons and the analytical uncertainties (Belousova et al., 2006a).  
378 Further discussion on the precision and accuracy of this method are expanded upon in (Griffin et al.,  
379 [2002](#); [2004](#); [Griffin et al., 2002](#)).

380 Calculation of depleted mantle model ages ( $T_{\text{DM}}$ ) for each zircon analysis were made using the  
381 measured  $^{176}\text{Lu}/^{177}\text{Hf}$  and modelled values for  $^{176}\text{Hf}/^{177}\text{Hf}_i = 0.279718$  at 4560 Ma and  $^{176}\text{Lu}/^{177}\text{Hf} =$   
382  $0.0384$  ([KromkhunGriffin et al., 20132000](#)). These values produce a depleted mantle model with  
383  $^{176}\text{Hf}/^{177}\text{Hf}_{(\text{present-day})} = 0.28325428325$ , comparable to average MORB ([Gum and Belousova,](#)  
384 [2006](#);[Nowell et al., 1998](#)). These single-stage model ages provide a minimum age on the source  
385 material from which the zircon crystallised. In addition, two stage model ages or crustal model ages  
386 ( $T_{\text{DM}}^c$ ) were calculated. These models assume that a zircon's parental magma was formed from  
387 average continental crust and therefore use a  $^{176}\text{Lu}/^{177}\text{Hf}$  ratio of 0.015 (Griffin et al., 2004)  
388 (Geochemical Earth Reference Model database) that was initially derived from the depleted mantle.

389

### 390 **3 Results**

#### 391 **3.1 Zircon descriptions**

392 The zircon grains (n=57) from sample Z3 are rounded and reddish-brown. Typical diameters range  
393 from 30- to 100  $\mu\text{m}$ . In ~90% of these zircons, morphologies are ~~characterise~~characterised by  
394 oscillatory zoned cores (Fig. [45a-b](#)) with isometric overgrowths and rims (6 rims >30  $\mu\text{m}$  in  
395 thickness). The additional 10% zircons have isometric morphologies with <15  $\mu\text{m}$  overgrowths.

396

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397 \*Insert Figure 4 here\*

398

399

400 Zircons from sample F (n=138) are predominantly brown, subhedral grains and are slightly larger  
401 than those in sample Z3 (~80% >70µm). The morphology of these zircons is predominantly  
402 characterised by oscillatory zoned cores (~75% of grains) with variable, weak to strongly zoned rims  
403 and isometric overgrowths (Fig. 45c-d).

404

405 Grains of zircon separated from sample 36 (n=32) are reddish-brown in colour and have a typical  
406 diameter range from 40-110 µm. The grains are subhedral and ~80% have oscillatory zoned cores  
407 (Fig. 5e-f). The remainder have isometric cores. ~10% of the grains have very thin overgrowths (<10  
408 µm).

409

410 The zircons separated from sample 123 (n=33) are indistinct in terms of colour, shape and size from  
411 the grains in sample F. ~Approximately 90% of the grains have oscillatory zoned cores. Very thin (<10  
412 µm) rims/overgrowths are apparent on ~30% of the grains (Fig. 45g-h).

413

414 ~~Grains of zircon separated from sample 36 (n=32) are reddish-brown in colour and have typical~~  
415 ~~diameter range from 40-110 µm. The grains are subhedral and ~80% have oscillatory zoned cores~~  
416 ~~(Fig. 4). The remainder have isometric cores. ~10% of the grains have very thin overgrowths (<10 µm).~~

417

418 The zircon grains from sample YD23a (n=29) are brown in colour, subhedral in shape, exhibit blunt  
419 pyramidal terminations, and vary in size between 100-300 µm. All of the zircon grains from this  
420 sample display oscillatory zonation and do not ~~have any~~ show any evidence for any metamorphic  
421 overgrowths (Fig. 45i-j).

422 Description of the Curnamona Province zircons from R1707876 (Frome Granite) and R1709059  
423 (Benagerie ~~Volcanics~~Volcanic Suite) can be found in Jagodzinski & Fricke (2010).

### 424 3.2 U-Th-Pb zircon geochronology

425 Results from LA-ICPMS U-Pb dating of ~~zircons presented in this study is~~zircon are presented in Table  
426 3. The complete dataset is provided in Supplementary Appendix A. Probability density plots and  
427 concordia plots for each of the samples analysed in this study are shown in Fig. 56-7.

428 \*Insert Table 3 here\*

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429 3.2.1 Z3 (Radium Creek Group - Brindana Schist)

430 A total of 78 zircon U-Pb analyses were conducted on 60 separate zircon grains. Data were gathered  
431 from both the cores and regions with clear oscillatory zoning for completeness (Fig. 46a-b). Six  
432 analyses from this total dataset were interpreted as metamorphic zircon growth (see Armit et al.,  
433 2012). ~~Armit et al. These authors (2012)~~ described these zircons as exhibiting isometric rims and  
434 overgrowths, yet only 3 of these analyses returned Th/U ratios <0.3 (an order of magnitude lower  
435 than the detrital igneous zircon cores presented here) and were less than 10% discordant. These  
436 metamorphic overgrowths have weighted mean  $^{207}\text{Pb}/^{206}\text{Pb}$  age of  $1552 \pm 32$  Ma ( $2\sigma$ ).

437

438 Fifty-four analyses from the remaining 72 are within 10% concordancy. The probability density plot  
439 for this sample has two major zircon population peaks (Fig. 56). The younger population consists of a  
440 group of 19 zircons which have a weighted mean  $^{207}\text{Pb}/^{206}\text{Pb}$  age of  $1595.7 \pm 9.2$  Ma ( $n = 19$ , MSWD =  
441 0.38,  $2\sigma$ ). An older population of 21 zircons has a weighted mean  $^{207}\text{Pb}/^{206}\text{Pb}$  age of  $1708 \pm 17$  Ma ( $n$   
442 = 21, MSWD = 1.9,  $2\sigma$ ). This peak consists of two separate populations (~~Isoplot unmix function~~  
443 ~~relative misfit = 0.967 based on 2 components~~), at  ~~$1687.8 \pm 8.8$  ca. 1680 Ma (1 $\sigma$ , 0.51 fraction)~~ and at  
444  ~~$1737 \pm 11$  ca. 1740 Ma (1 $\sigma$ , 0.49 fraction)~~. Three zircons with an age range of between ~~1765~~-~~ca. 1790~~  
445 ~~and ca. 1850~~ Ma were present in the sample. Archaean to earliest Palaeoproterozoic aged detrital  
446 zircons were also present in the sample and exhibit an age range of between ca. 2370 and ca. 2900  
447 Ma.

448

449 3.2.2 F (Radium Creek Group - Freeling Heights Quartzite)

450 A total of 148 U-Pb zircon analyses were conducted for this sample across 138 grains. Four of these  
451 analyses were located on zircon overgrowths/rims with isometric and/or 'fir-tree' and/or sector  
452 zoned morphology that were >30 $\mu\text{m}$  wide, and therefore could return signals uncontaminated by  
453 neighbouring domains, these are discussed in Armit et al. (2012). One hundred of the analyses from  
454 the remaining 144 igneous detrital zircon fraction were within 10% concordancy. The probability  
455 density plot of concordant analyses (<10% discordant) for this sample has 3 major peaks (Fig. 56c-d).  
456 The youngest population consists of 17 zircon grains and has a weighted mean  $^{207}\text{Pb}/^{206}\text{Pb}$  age of  
457  $1591.7 \pm 7.8$  Ma ( $n = 17$ , MSWD = 1.9,  $2\sigma$ ). An older peak is ~~comprised~~~~composed~~ of two distinct  
458 populations (Isoplot unmix ~~function relative misfit = 0.687 based on 2 components routine~~) at  ~~$1674.6$~~   
459  ~~$\pm 2.8$  ca. 1680 Ma (1 $\sigma$ , 0.56 fraction,  $n = 21$ )~~ and ~~a~~  ~~$1732.8 \pm 2.9$  at ca. 1730 Ma (1 $\sigma$ , 0.44 fraction,  $n =$~~   
460 ~~18)~~. A single grain from this sample returned a ca. 1841 Ma age. Eighteen analyses returned an age  
461 plateau between 2240 Ma and 2600 Ma. ~~A three component unmixing calculation (Isoplot unmix~~

462 ~~function relative misfit = 0.249), resolves these data into 3 populations aged at a 2295 ± 7.1 Ma (1σ,~~  
463 ~~0.11 fraction), 2449 ± 4 Ma (1σ, 0.53 fraction) and 2552 ± 4.5 Ma (1σ, 0.36 fraction).~~

464

### 465 3.2.3 123 (Radium Creek Group - Freeling Heights Quartzite)

466 U-Pb analysis was conducted on 40 separate detrital igneous-sourced zircons. Nine analyses were  
467 more than 10% discordant. Probability plots for the 31 remaining analyses are displayed in figure  
468 ~~56e-f~~. A tight cluster of late Mesoproterozoic zircon ages (n=8) have a weighted mean  $^{207}\text{Pb}/^{206}\text{Pb}$   
469 age of 1590 ± 6 Ma (n = 8, MSWD = 0.95, 2σ). ~~A three component unmixing calculation of the~~The  
470 remaining, older ages ~~(isoplot unmix function relative misfit = 0.410) resolves~~are characterised by  
471 Palaeoproterozoic populations at ~~1656 ± 4~~ca. 1660 Ma ~~(1σ, 0.38 fraction, n=6), 1704.4 ± 3.4,~~ ca.  
472 ~~1710 Ma (1σ, 0.5 fraction, n=7) and 1771.1 ± 6.7~~1770 Ma ~~(1σ, 0.13 fraction, n=2)~~. An Earliest  
473 Palaeoproterozoic population is also present and returns a weighted mean  $^{207}\text{Pb}/^{206}\text{Pb}$  age of 2490.1  
474 ± 9.9 Ma (n=4, MSWD = 0.41, 2σ).

### 475 3.2.4 36 (Radium Creek Group – Mount Adams Quartzite)

476 Thirty-nine analyses were conducted on 38 zircon grains for U-Pb ages from this sample of the  
477 Mount Adams Quartzite- (Fig. 6g-h). One analysis is >10% discordant. The youngest ~~population~~  
478 distinguishable ~~population~~ from the remaining 38 analyses is a cluster at 1592 ± 10 Ma (n = 8, MSWD  
479 = 1.4, 2σ). ~~A three component unmixing calculation of the remaining, older ages resolves (isoplot~~  
480 ~~unmix function relative misfit = 0.549)Other population~~ peaks are evident at ~~1677.7 ± 3.3~~ca. 1680  
481 Ma ~~(1σ, 0.42 fraction), 1709.9 ± 4.1,~~ ca. 1710 Ma ~~(1σ, 0.30 fraction) and 1743.8 ± 3.3~~ca. 1740 Ma  
482 ~~(1σ, 0.27 fraction)~~. An older, Earliest Palaeoproterozoic population has a weighted mean  $^{207}\text{Pb}/^{206}\text{Pb}$   
483 age of 2477.1 ± 11 Ma (n=3, MSWD = 2.2, 2σ).

484 ~~\*Insert Figure 5 here\*~~

### 485 3.2.5 YD23a (upper Gawler Range Volcanics)

486 A total of 33 analyses were conducted on 29 separate zircons grains. 26 of these are ≤10%  
487 discordant. No concordia age or intercept age could be satisfactorily determined using the entire  
488 population. In addition, the weighted mean  $^{207}\text{Pb}/^{206}\text{Pb}$  age for the entire group (Fig. 6j) produced  
489 an MSWD >8. The very high MSWD implies the presence of inherited zircon populations. These are  
490 calculated using probability plots and unmixing models to have ages of ca. 1680 ± 24 Ma and ca.  
491 ~~1762 ± 22~~1760 Ma. These analyses correlate with dark core regions in CL images, which  
492 independently ~~suggests~~suggest that they should not be included in a weighted crystallisation age  
493 calculation. Instead we prefer the weighted mean  $^{207}\text{Pb}/^{206}\text{Pb}$  age of 1595 ± 19 Ma (n = 17, MSWD =  
494 0.046, 2σ), which is consistent with the previously published age of the Yardea Dacite (upper Gawler

495 Range Volcanics:  $1592 \pm 3$  Ma; Fanning et al., 1988) as well as the lower units of the Gawler Range  
496 Volcanics  $1591 \pm 3$  Ma (Fanning et al., 1988).

497 [\\*Insert Figure 6 here\\*](#)

### 498 3.3 In-situ Lu-Hf

499 A total of 74 zircon grains were analysed from the Radium Creek Group. This included 37 grains from  
500 the pelitic Brindana Schist, 18 from the overlying Freeling Heights Quartzite and 19 from the Mount  
501 Adams Quartzite- (Fig. 8a-b). Twenty-five grains were analysed from the upper Gawler Range  
502 Volcanics (Central Gawler Craton; YD23a) ~~were conducted~~(Fig. 8c). Twenty-two grains with 2  
503 repeats [from the same domain] were analysed from the Frome Granite (Fig. 8c), and 13 zircon  
504 grains from the rhyolitic Benagerie ~~Volcanics~~Volcanic Suite (Fig. 8c) (Curnamona Province; R1707876  
505 and R1709059 respectively). These results are presented in Table 3 and summarised in ~~Fig. 7~~Figure  
506 [8a-d](#) (the full dataset is presented in Appendix A).

507 [\\*Insert Figure 7 here\\*](#)

#### 508 3.3.1 Z3 (Radium Creek Group - Brindana Schist)

509 Hf isotope ratios measured from the ca. 2900 Ma (Archaean) zircon grain has a  $\epsilon$  Hf<sub>(t)</sub> value of +7.27  
510 and a crustal model age ( $T_{DM}^c$ ) of 2880 Ma- (Fig 8a-b). Early Palaeoproterozoic zircon grains that are  
511 dated at 2300 and 2500 Ma have  $\epsilon$  Hf<sub>(t)</sub> of -4.89 and -1.11, and  $T_{DM}^c$  at ~~3.113110 Ma~~ to 3240 Ma  
512 respectively- (Fig. 8a-b). Zircon grains with ages between 1765 Ma and 1850 Ma (n=3) possess an  
513  $\epsilon$  Hf<sub>(t)</sub> range from -4.9 to -2.89 and  $T_{DM}^c$  ages between 2660 and 2800 Ma. Zircon grains with ca.  
514 1710-1760 Ma dates have initial  $\epsilon$  Hf values that are scattered between -6.58 and +2.74 (n=6).  $T_{DM}^c$   
515 ages for these ca. 1710-1760 Ma zircons range from 2280 to 2840 ~~Ga~~Ma. A continuum of initial  
516  $\epsilon$  Hf<sub>(t)</sub> values from -4.21 to +5.8 characterise zircon grains with ages ca. 1630-1690 Ma (n=11) and  
517 correspond to  $T_{DM}^c$  ages between 2000 and 2630 Ma. The youngest population ca. 1595 Ma has a  
518  $\epsilon$  Hf<sub>(t)</sub> range between -6.7 and +2.77 (n=14) (Fig. 8a) and  $T_{DM}^c$  from 2150 to 2750 Ma- (Fig. 8b).

#### 519 3.3.2 F (Radium Creek Group - Freeling Heights Quartzite)

520 The ca. 2500 Ma zircon grains (n=2) have  $\epsilon$  Hf<sub>(t)</sub> values of -5.15 and +1.29 ( $T_{DM}^c$  values of 3.38 and  
521 ~~2.97 Ga~~2970 Ma respectively) (Fig. 8a-b). A single grain with an age of ca. 1841 Ma has a  $\epsilon$  Hf<sub>(t)</sub> of -  
522 2.56 and a  $T_{DM}^c$  of 2680 Ma. A ca. 1730 Ma population s (n=8) records  $\epsilon$  Hf<sub>(t)</sub> values ranging from -9.4  
523 to -0.53,  $T_{DM}^c$  for this group are 2480 to 3030 ~~Ga~~Ma. Zircons with U-Pb ages of ca. ~~16791680~~ Ma  
524 (n=3) have a range of  $\epsilon$  Hf<sub>(t)</sub> values from -9.91 to 0 and  $T_{DM}^c$  from 2390 to 3000 Ma. An early  
525 Mesoproterozoic population ca. 1595 Ma (n=4) have  $\epsilon$  Hf<sub>(t)</sub> values ranging from -6.11 to +2.44 (Fig.  
526 [8a](#)) and  $T_{DM}^c$  between 2170 and 2720 Ma- (Fig. 8b).

527 3.3.3 36 (Radium Creek Group – Freeling Heights Quartzite)

528 This sample includes grains from 5 discrete age populations. All but the youngest (the early  
529 Mesoproterozoic population) have negative  $\varepsilon \text{Hf}_{(t)}$  values- (Fig. 8a). The oldest grain ca. 2948 Ma has  
530 a  $\varepsilon \text{Hf}_{(t)}$  value of -9.46 and a  $T_{\text{DM}}^{\text{c}}$  of [3.973970 Ma](#). A ca. 2500 Ma population (n=2) has initial  $\varepsilon \text{Hf}$   
531 values of -2.77 and -0.93 ( $T_{\text{DM}}^{\text{c}}$  values of 3220 and 3070 Ma respectively). Ca. 1850 Ma (n=2) zircon  
532 grains have  $\varepsilon \text{Hf}_{(t)}$  values of -6.32 and -3.24 (Fig. 8a) with  $T_{\text{DM}}^{\text{c}}$  of 2730 and 2940 Ma respectively- (Fig  
533 8b). Grains at ca. [17001710](#)-1740 Ma (n=4) return a tight cluster of initial  $\varepsilon \text{Hf}_{(t)}$  values that range  
534 between -3.63 and -2.07. This group have  $T_{\text{DM}}^{\text{c}}$  from 2540 to 2670 Ma. A ca. 1677 Ma (n=3)  
535 population have a  $\varepsilon \text{Hf}_{(t)}$  value range of -3.82 to -1.07 and  $T_{\text{DM}}^{\text{c}}$  between [2.452450](#) and 2630 Ma. A  
536 ca. 1595 Ma (n=7) population have a spread of  $\varepsilon \text{Hf}_{(t)}$  values ranging from -5.37 to +2.79 (Fig 8a) and  
537 corresponding  $T_{\text{DM}}^{\text{c}}$  of 2130 to 2690 Ma- (Fig 8b).

538 3.3.4 YD23a (upper Gawler Range Volcanics)

539 This sample has 4 U-Pb age clusters. The principle age population (ca. 1595 Ma, n=20) ranges  
540 between -4.51 and -0.82,  $T_{\text{DM}}^{\text{c}}$  range of 2380-2620 Ma with an outlier that returned a  $\varepsilon \text{Hf}_{(t)}$  value of  
541 +3.01 and 2250 Ma  $T_{\text{DM}}^{\text{c}}$ - (Fig. 8c).  $\varepsilon \text{Hf}_{(t)}$  of grains older than ca. [17001710](#) Ma (n=4) range between  
542 +1.61 and +2.81,  $T_{\text{DM}}^{\text{c}}$  ranges from 2300-2430 Ma.  $\varepsilon \text{Hf}_{(t)}$  values of ca. [16551680](#) Ma (n=2) zircon  
543 grains are -1.14 and -0.98,  $T_{\text{DM}}^{\text{c}}$  ~~range are ages of~~ 2440 and 2450 Ma- (Fig. 8c).

544 3.3.5 R1707876 (Curnamona Province: Frome Granite) – [Bimbowrie Suite](#)

545 The dominant population at  $1594 \pm 8$  Ma (n=22; Jagodzinski and Fricke, 2010) have  $\varepsilon \text{Hf}_{(t)}$  values  
546 ranging from -5.29 to +1.02 and  $T_{\text{DM}}^{\text{c}}$  between 2260 and 2670 Ma- (Fig 8c). A single older grain ca.  
547 1640 Ma has an  $\varepsilon \text{Hf}_{(t)}$  value of -2.7 and  $T_{\text{DM}}^{\text{c}}$  of 2.53 Ga. A young grain ca. 1557 Ma has a distinctly  
548 positive  $\varepsilon \text{Hf}_{(t)}$  value of +5.96 and  $T_{\text{DM}}^{\text{c}}$  of 1920 Ma.

549 3.3.6. R1709059 (Curnamona Province: Benagerie [Volcanics](#)) – [1587 ± 6 Ma Volcanic Suite](#)

550 The single population ca. 1587 Ma calculated for this rhyolite (Jagodzinski and Fricke, 2010) recorded  
551 a range of  $\varepsilon \text{Hf}_{(t)}$  values from -1.7 to +4.0 and  $T_{\text{DM}}^{\text{c}}$  between 2070 and 2440 Ma- (Fig. 8c).

552 **3.4 In-situ trace element chemistry**

553 The modelled rock type for each zircon analysed using the classification scheme of Belousova et al.  
554 (2002) are shown in Table 4 and are shown graphically in [Fig-8Figure 9](#). In both samples modelled (F  
555 and 36), three modelled rock types for all of the zircons analysed were distinguished. These were  
556 low  $\text{SiO}_2$  granitoids, granitoids (70-75 wt%  $\text{SiO}_2$ ) and dolerites.

557 [\\*Insert Table 4 here\\*](#)

558 The ca. 1595 Ma zircons in sample F (Freeling Heights Quartzite) were modelled as originating from  
559 low SiO<sub>2</sub> granitoids (n=2) and from moderate SiO<sub>2</sub> content (70-75 wt%) granitoids (n=1). The ca.  
560 1650-1680 Ma population was modelled as dolerite and 70-75 wt% granitoid (n=2). A subset of 8  
561 zircons from the ca. 1700-1740 Ma zircon population indicates a predominantly granitoid source  
562 rock (n=5), although two zircons modelled as being sourced from dolerite (n=2) and 1 from a low  
563 SiO<sub>2</sub> granitoid. The ca. 1800-1850 [Ma](#) and [Earliest](#) Palaeoproterozoic populations were  
564 modelled as wholly 70-75 wt% SiO<sub>2</sub> granitoid derived. The overall modelled rock type source  
565 distributions for this sample [was](#) 62.5% granitoid (70-75 wt% SiO<sub>2</sub> content) derived (n=10/16)  
566 and 18.75% from both dolerite and low SiO<sub>2</sub> (<65 wt%) granitoids.

567 The ca. 1595 Ma zircons in sample 36 (Mount Adams Quartzite) model as being derived from both  
568 low (n=2) and moderate (n=3) SiO<sub>2</sub> content granitoids. The ca. 1650-1680 Ma grains in this sample  
569 are evenly sourced from dolerite and 70-75 wt% SiO<sub>2</sub> granitoid rock types, which is identical to  
570 sample F. The ca. 1700-1740 Ma grains in this sample (n=3) are similar to those from that in [the](#)  
571 [Sample](#) F, as two are modelled as granitoid (70-75 wt% SiO<sub>2</sub>), and the third as dolerite  
572 sourced zircon, but lack zircons derived from low SiO<sub>2</sub> granitoids. It is possible this is due to sample  
573 size. One zircon in the 1800-1850 Ma population is derived from a low silica granitoid, and the other  
574 to a moderate SiO<sub>2</sub> content granitoid. The Archaean portion of the zircons analysed from this sample  
575 are sourced from a granitoid with 70-75 wt% SiO<sub>2</sub> content (n=3) or from a dolerite (n=1). The total  
576 modelled rock type source distributions for this sample was 61.1% granitoid (70-75 wt% silica  
577 content) derived (n=11/18), 22.2% dolerite derived (n=4/18) and 16.67% from low silica granitoids  
578 (n=3/18).

579 [\\*Insert Figure 8 here\\*](#)

### 580 **3.5 Whole rock geochemistry**

581 Complete major and trace element data is presented in supplementary appendix B. Major element  
582 data [defines](#) sample Z3 as shale and sample F as subarkose according to the classification of  
583 Herron (1998). Th/Sc ratios for each of [sample](#) Z3 and [sample](#) F are 2.506 and 2.23  
584 respectively. The samples display negative Eu/Eu\* anomalies (Taylor & McLennan, 1985) of 0.41 for  
585 sample Z3 and 0.575 for sample F. Sample Z3 has a La/Yb<sub>n</sub> value of 6.05 and sample F has a value  
586 (La/Yb<sub>n</sub>) value of 1.08.

## 587 **4 Discussion**

### 588 **4.1 Implications of new Radium Creek Group U-Pb zircon ages**

589 In-situ U-Pb zircon dating of the Radium Creek Group units yielded a distinct Early Mesoproterozoic  
590 population within analytical uncertainty of each other. The 4 samples in this study yield a weighted

591 mean average  $^{207}\text{Pb}/^{206}\text{Pb}$  age of  $1595.5 \pm 3.7$  Ma ( $n=41$ ), which can be interpreted as the maximum  
592 depositional age of the Radium Creek Group. This robust age is within error of the SHRIMP IIe U-Pb  
593 maximum depositional ages of  $1600 \pm 8$  Ma (Palaeoproterozoic suite 4; Teale, 1993) and  $1591 \pm 6$   
594 Ma (Palaeoproterozoic suite 5; Teale, 1993) for quartzofeldspathic gneisses sampled in the Paralana  
595 Creek ~10 kilometres to the south of the current study (Fraser and Neumann, 2010). Since we find  
596 these early Mesoproterozoic depositional ages to be prominent throughout the Radium Creek  
597 Group, we ~~regard~~[interpret](#) a geological framework involving a single phase of deposition for the  
598 entire package (Coats and Blissett, 1971; Elburg et al., 2001) at ca. 1595 Ma rather involving two  
599 distinct phases [as previously interpreted](#) (Paul, 1998; Teale 1993) ~~to be most appealing.~~ This single  
600 depositional episode model is consistent with the structural framework interpreted by Armit et al.  
601 (2012) who described an upwards coarsening sequence from basal pelitic units (Brindana Schist)  
602 conformably overlain by quartzites and conglomerates of the Freeling Heights Quartzite (Fig. [910](#)).

603 [\\*Insert Figure 9 here\\*](#)

604 The overall detrital zircon U-Pb population distributions (Fig. [56](#)) for all 4 Radium Creek Group  
605 samples in this study, are very similar to each other; with significant U-Pb age contributions at ca.  
606 1595 Ma, ca. ~~1650~~[1660](#)-1680 Ma, ca. 1710-~~1760~~[1780](#) Ma and ca. 2500 Ma. Moreover, the in-situ  
607 zircon geochemistry of zircons from both the hanging wall (Freeling Heights Quartzite; sample F) and  
608 the footwall (Mount Adams Quartzite; sample 36) of the Paralana Fault is remarkably similar (Fig.  
609 [89](#)). Modelling of these zircon grain's geochemistry classifies the population as predominantly  
610 derived from felsic magmatism, but both units also have a small component of more mafic derived  
611 magmatic zircons of ca. ~~1650~~[1660](#)-1680 Ma and ca. ~~1700-1760~~[1710-1780](#) Ma age.

612 Our data support the suggestion of comparable provenance for these units, and by extension, the  
613 Radium Creek Group across the fault. The most straightforward explanation is that entire group  
614 shares the same provenance. On this basis we interpret a source terrane for the Radium Creek  
615 Group that contains ca. 1595 Ma intermediate to felsic magmatic rocks and reworked older  
616 Archaean to Palaeoproterozoic mafic to felsic magmatic material.

617 In addition, a subordinate U-Pb population at ca. 1850 was discovered in both the Freeling Heights  
618 Quartzite (Sample F) and the Mount Adams Quartzite (sample 36). These quartzites have been  
619 previously interpreted as distinct units; the Mount Adams Quartzite forming an older unit in the  
620 stratigraphy (Coats and Blissett, 1971). The lower Freeling Heights Quartzite has also been  
621 interpreted to be significantly older than the upper Freeling Heights Quartzite and Mount Adams  
622 Quartzite on the basis of stronger deformation recorded in these lower horizons (Paul et al., 1999).

623 Our data suggest these differences in deformation intensity may be due to factors other than a time  
624 break, as the indistinguishable maximum depositional ages for these two units and the similarities in  
625 both the dominant and subordinate U-Pb detrital populations (i.e. ca. 1850 Ma) would suggest that  
626 these quartzites are likely to be lateral correlatives to each other. The greater deformation intensity  
627 observed within the lower parts of the Freeling Heights Quartzite could instead be explained by the  
628 location of the Freeling Heights Quartzite in the ~~hanging wall~~ [hangingwall](#) of the Paralana Fault,  
629 whilst the Mount Adams Quartzite is restricted to the footwall (Fig. [23](#)). Strain partitioning related to  
630 protracted shearing along the Paralana Fault is suggested to result in the development of more  
631 intense deformation in the proximal parts of hangingwall to the fault.

632 The lower horizons of the Freeling Heights Quartzite are slightly more micaceous than the upper part  
633 of the unit and to the Mount Adams Quartzite (Armit, 2007). In particular, proximal to the contact  
634 with the underlying Brindana Schist, the Freeling Heights Quartzite contains large micaceous pods in  
635 which strain has been localised during Mesoproterozoic and Palaeozoic deformation (Armit et al.,  
636 2012) producing a stronger structural fabric than is evident at the meso-scale in the upper horizons  
637 of the Freeling Heights Quartzite and in the Mount Adams Quartzite. According to this single  
638 deposition framework the entire ca. 1595 Ma Radium Creek Group is deformed by ca. 1591-1585 Ma  
639 deformation (~~D<sub>1</sub>-D<sub>2</sub>~~) and is not sub-divided into pre- and post-deformational sequences (c.f. Fanning  
640 et al., 2003; Paul, 1998; Paul et al., 1999).

#### 641 **4.2 Whole rock geochemistry**

642 Th/Sc ratios for ~~each of samples~~ [sample](#) Z3 and [sample](#) F are higher than Post Archaean Australian  
643 Shale- (PAAS, Th/Sc = 0.91; Taylor & McLennan, 1985) which supports the interpretation from the  
644 in-situ zircon geochemistry that both of these samples were most likely sourced from a region  
645 dominated by felsic material (Bhatia & Cook 1986; Cullers & Berendsen 1998). The samples display  
646 moderately negative Eu/Eu\* anomalies (0.41 for sample Z3 and 0.575 for sample F) when compared  
647 to PAAS (0.65; Taylor & McLennan, 1985). This indicates their source was also characterised by  
648 negative Eu anomalies, a ubiquitous ~~feature~~ [affinity](#) of A-type magmatic suites. La/Yb<sub>n</sub> ratios of 6.05  
649 for sample Z3 indicate it is slightly LREE enriched. Sample F (~~La/Yb<sub>n</sub> value of 1.08~~) displays significant  
650 HREE enrichment, (~~La/Yb<sub>n</sub> value of 1.08~~), which is most likely due to accumulation of [previously](#)  
651 [mobile](#) HREE in garnets that grew as a result of regional metamorphism at ca. 1591-~~155Ma~~ [1552Ma](#)  
652 (Armit et al. 2012).

#### 653 **4.3 In-situ Hf Isotopes**

654 Hf isotope signatures of the Radium Creek Group samples are fairly diverse and most likely reflect  
655 both ~~crustally~~ less evolved and substantially more evolved signatures (Fig. [78a-b](#)). Within each U-Pb  
656 age population, considerable overlap in the Hf isotope ratios is present across the ~~three~~ [three](#) Mount

657 | Painter samples (Table 3). ~~Our~~These data strengthens the argument that both the pelitic and more  
658 | quartz-rich units of the Radium Creek Group are of the same provenance.

659 | The ca. 1595 Ma U-Pb population within the Radium Creek Group samples (n=25, this study) in the  
660 | northern Mount Painter Inlier is consistent with the spread in Hf isotope ratios of the Early  
661 | Mesoproterozoic aged grains (n=4) in sample ARK661 ~~which is~~(Fig. 8c-d), from the southern Mount  
662 | Painter Inlier (Elburg et al. 2012). This strengthens ~~support~~ for the interpretation of a similar  
663 | provenance for all of the Early Mesoproterozoic metasediments in the Mount Painter Inlier. Our  
664 | larger dataset both confirms the maximum depositional age for the Radium Creek Group, and  
665 | demonstrates for the first time a clear bimodal  $\epsilon$  Hf<sub>(t)</sub> signature for this population. Mixing between  
666 | an evolved component ( $\epsilon$  Hf<sub>(1595)}</sub> -6.7 to -1.17, n=16) and a more juvenile component ( $\epsilon$  Hf<sub>(1595)}</sub> 0 to  
667 | +2.79, n=9) is consistent with this pattern- (Fig. 8d).

668 | ~~Due to the overwhelming preponderance of igneous derived detrital zircons, we are able to focus on~~  
669 | ~~magmatic packages. This allows robust comparison with neighbouring tectonic elements, which we~~  
670 | ~~now turn our attention to.~~

671 | The magmatic pulse that generated the detrital source material of the Radium Creek Group must  
672 | have contained a juvenile component, but also recrystallised more evolved material.  
673 | Contemporaneous melting of various mantle and crust is consistent with the bimodal Hf isotope  
674 | data in the resultant sedimentary packages. The Early Mesoproterozoic U-Pb age population peak  
675 | (ca. 1595 Ma) within the age spectra of neighbouring felsic-dominated magmatic rocks; the upper  
676 | Gawler Range Volcanics (sample YD23a), Frome Granite and Benagerie ~~Volcanics~~Volcanic Suite,  
677 | therefore invite  $\epsilon$  Hf<sub>(t)</sub> comparison with the Radium Creek Group- (Fig. 8c).

678 | The predominantly negative  $\epsilon$  Hf<sub>(1595Ma)}</sub> values (-4.51 to -0.82) of the upper Gawler Range Volcanics  
679 | ~~zircon~~zircons (Fig. 8c) would suggest (prima facie) that it was formed from moderately evolved  
680 | crustal material. However the single, positive  $\epsilon$  Hf<sub>(1595Ma)}</sub> value implies more juvenile material was  
681 | also involved to a degree. Pankhurst et al. (2013) report whole-rock Hf data for the small volume  
682 | mafic components of the Gawler Range Volcanics which record a more primitive signal ~~that~~than we  
683 | observe within our zircon population. This demonstrates that a juvenile component of the Gawler  
684 | Range Volcanics can be detected, and that its weak contribution to subsequent basin detritus may  
685 | be muted by lack of mafic outcrop in the hinterland.

686 | The Hf isotope signature of the upper Gawler Range Volcanics is ~~not dissimilar~~similar to that of the  
687 | ca. 1595 Ma detrital zircons from the Radium Creek Group, as their absolute range of  $\epsilon$  Hf<sub>(1595Ma)}</sub>  
688 | values overlap- (Fig. 8c). However, the Radium Creek Group data extends to both more evolved and

689 strongly negative  $\epsilon_{\text{Hf}(1595\text{Ma})}$  values. This might reflect a sampling bias (e.g. Andersen et al. 2005) or  
690 that the source terrane of the Radium Creek Group ca. 1595 Ma zircon peak has a greater isotopic  
691 heterogeneity than the preserved Gawler Range Volcanics alone.

692 Zircon grains with ca. 1595 Ma ages from the Frome Granite ([Bimbowrie Suite](#)) indicate that this  
693 magma formed at least in part from reworked crust of ca. 2260-2670 Ma ([Fig. 8c](#)). The signature is  
694 similar to the range of  $\epsilon_{\text{Hf}(1595\text{Ma})}$  values from the upper Gawler Range Volcanics grains, as they also  
695 record predominantly negative values to weakly positive (-5.29 to +1.02) ([Fig. 8c](#)). Similarly, this  
696 range of values falls within that of the Radium Creek Group. Importantly, >1650 Ma U-Pb  
697 populations are absent from our data. Moreover the Frome Granite intrusive age of  $1594 \pm 8$  Ma  
698 (Jagodzinski and Fricke, 2010) would suggest that it would have been located within the crustal pile  
699 during the earliest Mesoproterozoic and hence unlikely to be actively eroding to provide the  
700 required detritus into a nascent ca. 1595 Ma basin now preserved in the Mount Painter Inlier.

701 The Hf isotope signature of the ca. 1595 Ma zircon populations in the Benagerie ~~Volcanics~~[Volcanic Suite](#)  
702 sample is defined by a relatively tightly clustered group of  $\epsilon_{\text{Hf}(1595\text{Ma})}$  values (-1.73 to +4.0). This  
703 group is appreciably more juvenile than the ~~ranges~~[values](#) for the upper Gawler Range Volcanics and  
704 Frome Granite. ~~Importantly, the range extends~~ ([Fig. 8c](#)). ~~It is important to more juvenile values than~~  
705 ~~those recorded in zircon grains within~~ ~~note that unlike~~ the Radium Creek Group, ~~we did not detect a~~  
706 ~~more evolved and negative Hf component (-6 to -2) in this sample of Benagerie Volcanic Suite~~ ([Fig.](#)  
707 [8c](#)).

708 -The lack of a good match between the Benagerie ~~Volcanics~~[Volcanic Suite](#) and Radium Creek Groups  
709 zircon Hf isotope signature ([Fig. 8c](#)) implies that provenance of the metasediment within the Mount  
710 Painter Inlier is unlikely to include the Benagerie ~~Volcanics~~[Volcanic Suite](#). The ca. 1587 Ma  
711 crystallisation age calculated for this sample (Jagodzinski and Fricke, 2010) is also slightly younger  
712 ~~of than~~ the maximum deposition age (ca. 1595 Ma) of the Radium Creek Group (although within  
713 analytical uncertainty). Rather, this age has greater similarity with the age of the Mount Neill Suite  
714 magmatism in the Mount Painter Inlier (ca. 1585 Ma). This suite intrudes the metasediments  
715 following an episode of burial and deformation at ca. 1595-1585 Ma (Armit et al., 2012). Thus if the  
716 Benagerie ~~Volcanics~~[Volcanic Suite](#) are extrusive equivalents of the magmatic pulse that generated  
717 the Mount Neill Suite, it would not be feasible for these rocks to contribute to the source of the  
718 Radium Creek Group.

719 Thus a combination of Hf isotope data and geologic evidence, effectively remove the Curnamona  
720 Province felsic magmatic rocks with ca. 1595 ages (Frome Granite and Benagerie ~~Volcanics~~[Volcanic Suite](#))

721 | [Suite](#)) from consideration as potential sources of the Radium Creek Group. The remaining sample is  
722 | the Gawler Range Volcanics sample. The following discussion aims to explore this hypothesis.

723 | The prominent ca. 1680-~~1650~~[1660](#) Ma detrital zircon U-Pb population within the Radium Creek  
724 | Group has a grouped  $\epsilon$  Hf<sub>(t)</sub> value range of -9.91 to +5.8 (n=17). A similar spread of values is evident  
725 | in ARK661 (Elburg et al., 2012) with  $\epsilon$  Hf<sub>(t)</sub> values of between -7 to +6.7 (n=9) ([Fig. 8c-d](#)). A source  
726 | terrane for this scattered and highly variable Hf isotope signature is likely to be ~~comprised~~[composed](#)  
727 | of reworked, refractory ca. 3000-2400 Ma Archaean to Palaeoproterozoic crust which has mixed  
728 | with significantly more isotopically primitive material ca. 1680-~~1650~~[1660](#)Ma.

729 | Two zircons from the upper Gawler Range Volcanics have U-Pb ages ca. 1655 Ma and therefore  
730 | match the age peak within the Radium Creek Group. These two grains record slightly negative  $\epsilon$  Hf<sub>(t)</sub>  
731 | values. While these are within the  $\epsilon$  Hf<sub>(t)</sub> range for the corresponding Radium Creek Group age peak;  
732 | it is difficult to ascribe much significance given the size of the data subset.

733 | No pre-1650 Ma U-Pb population was identified from either the Frome Granite or Benagerie  
734 | Volcanic samples (Jagodzinski and Fricke, 2010). ~~The~~[It is worth noting that the](#) absence of a ca. ~~1650-~~  
735 | ~~80~~[1660-1680](#) age peak in these samples ~~may also imply~~[strengthens the argument](#) that the pre-1650  
736 | Ma zircons in the Radium Creek Group cannot have been sourced from these magmatic suites.

737 | Detrital zircons that define a U-Pb population at ca. 1710-~~1760~~[1780](#) Ma in the Radium Creek Group  
738 | have a relatively evolved Hf isotopic signature, although an appreciably juvenile signal is also present  
739 | ( $\epsilon$  Hf<sub>(t)</sub> ranges between -9.4 to +2.74; n=18). Any potential sources for this detritus are interpreted to  
740 | be ~~comprised~~[composed](#) of predominantly reworked and refractory ca. 3030-2680 Ma Archaean to  
741 | Palaeoproterozoic crust that has mixed with slightly more isotopically juvenile material ( $T_{DM}^c$  of 2280  
742 | Ma) at ca. 1710-~~1760~~ Ma. ~~In all of the Radium Creek Group samples in this study, zircons analyses~~  
743 | ~~from this ca. 1710-1760 Ma U-Pb age bracket are spread between ca. 1711 Ma and ca. 1783 Ma (Fig.~~  
744 | ~~5). Only a single analysis from the metasediment sample ARK661 (661-40) of Elburg et al. (2012) has~~  
745 | ~~a U-Pb age within this range (ca. 1711 Ma). This grain has a similar, distinctly evolved Hf signature~~  
746 | ~~( $\epsilon$  Hf = -10.4). The lack of other grains of similar age in this sample could be an artefact of small~~  
747 | ~~sample size (Andersen, 2005).~~[1780 Ma.](#)

748 | ~~Zircons from the ca. 1650-1680 and ca. 1710-1760 Ma populations in the Radium Creek Group which~~  
749 | ~~modelled as having mafic derived in-situ geochemistry affinities did not exhibit positive (more~~  
750 | ~~primitive)  $\epsilon$  Hf<sub>(t)</sub> values. This would suggest that in terms of their isotope ratios, these mafic derived~~  
751 | ~~zircon grains reflect crustal contamination processes, or metasomatised mantle, rather than~~  
752 | ~~derivation from the depleted mantle.~~

753 | The three zircons ca. 1710-~~1790~~1780 Ma from the upper Gawler Range Volcanics all record positive  
754 |  $\epsilon$  Hf<sub>(t)</sub> (+1.61 to +2.73), which is similar to the small (n=2; +0.08, +2.73) juvenile component within  
755 | the ca. 1710-~~1760~~1780 Ma Brindana Schist of the Radium Creek Group- (Fig. 8c). Unlike the Radium  
756 | Creek Group however, we ~~were unable to find and did not detect a~~ more evolved Hf component of ca.  
757 | 1710-~~1760~~1780 Ma age in sample YD23a. Larger U-Pb-Hf ~~in~~ zircon datasets for the upper Gawler  
758 | Range Volcanics may resolve this Hf isotope mis-match. ~~The complete lack of similar aged ca. 1710-~~  
759 | ~~1760 Ma inherited zircon populations in either the Frome Granite or Benagerie Volcanics further~~  
760 | ~~supports that they are unlikely to be the sole source of detrital zircons in the Radium Creek Group.~~

761 | All of the ca. 1850 Ma zircons analysed (n=4) from the Radium Creek Group in this study have  
762 | isotopically evolved Hf signatures, interpreted as reworked ca. 2680-2940 Ma Archaean material-~~A~~  
763 | ~~slightly older ca. 1904 Ma U-Pb population (n=2) from ARK661 have appreciably juvenile  $\epsilon$  Hf<sub>(t)</sub>~~  
764 | ~~values (+3.02 & +4.53; Elburg et al. 2012), and reflect reworking of ca. 2280-2370 Ma Early~~  
765 | ~~Palaeoproterozoic crust. (Fig. 8a).~~ The ~~6~~six Hf isotope analyses ~~on~~from ca. 2500 Ma ~~zircon~~zircon  
766 | grains have a  $\epsilon$  Hf<sub>(t)</sub> value range between -5.15 and +1.29 reflecting reworked >2970 Ma Archaean  
767 | crust. Archaean zircon in sample ARK661 (n=5) have overlapping to moderately more juvenile Hf  
768 | isotopic signatures with respect to the other sample of Radium Creek Group and are characterised  
769 | by  $\epsilon$  Hf<sub>(t)</sub> values ranging between -0.35 and +4.12 (Fig. 8d) ( $T_{DM}^c$  range of 2820-3110 Ma). This most  
770 | likely reflects a large isotopic heterogeneity in the Archaean component of the source terrane for  
771 | the metasediments in the Mount Painter Inlier.

772 | It is important to note the small sample populations of zircon grains (n <4) representing the ca.  
773 | 1710-1780 Ma and ca. 1850 Ma ages. It is therefore possible that the Hf isotopic signatures of these  
774 | populations may not be truly representative.

#### 775 | **4.4 Whole rock Nd isotopes**

776 | Whole rock Nd isotope ratios of the Freeling Heights Quartzite and Yaglin Phyllite units of the  
777 | Radium Creek Group (Neumann, 2001; Schaefer, 1993) have been recalculated to 1595 Ma to reflect  
778 | the maximum depositional age of these units determined in this study. The result is negative  
779 |  $\epsilon$ Nd<sub>(1595)</sub> values of -5.19 to -3.25 (Freeling Heights Quartzite) and -4.36 (Yaglin Phyllite). This is  
780 | consistent with the predominantly negative in-situ Hf isotopic signature presented in this study for  
781 | the ca. 1595 Ma Radium Creek Group.

782 | The  $\epsilon$ Nd<sub>(1585)</sub> values of the felsic upper Gawler Range Volcanics range from -4.3 to -1.8, and as such  
783 | are indistinguishable from those of the Benagerie ~~Volcanics~~Volcanic Suite (Wade et al., 2012). The  
784 | felsic rocks of the lower Gawler Range Volcanics contain more variable values of  $\epsilon$ Nd<sub>(1585)</sub>, and range  
785 | from evolved ( $\epsilon$ Nd<sub>(1585)</sub> of -7) to less evolved ( $\epsilon$ Nd<sub>(1585)</sub> of -0.2) signals (Wade et al., 2012). The

786 Radium Creek Group contains slightly more evolved  $\epsilon\text{Nd}_{(1595)}$  (e.g. -5.19 for the Freeling Heights  
787 Quartzite) and disperse  $\epsilon\text{Hf}_{(1595)}$  values than the upper Gawler Range or Benagerie  
788 [Volcanics/Volcanic Suite](#). We suggest that isotopic correlation between the Radium Creek Group and  
789 the more diverse negative  $\epsilon\text{Nd}_{(1585)}$  values for the lower Gawler Range Volcanics is more consistent.

790 The in-situ zircon age spectra and contained  $\epsilon\text{Hf}_{(t)}$  coupled with geologic context and whole-rock  
791  $\epsilon\text{Nd}$  support a Gawler Craton dominated provenance for the Radium Creek Group. The Curnamona  
792 Province contains appropriate felsic magmatic rocks of a similar age to that of the maximum Radium  
793 Creek Group deposition age, however, several lines of evidence preclude a Curnamona Province  
794 provenance for the Radium Creek Group.

795

#### 796 [4.5 Proterozoic tectonic implications](#)

##### 797 [4.5 Comparison with regional datasets](#)

798 The present location of the Mount Painter Inlier within the northern South Australia Craton ([Fig. 1a-](#)  
799 [b](#)) and relative proximity to both the Curnamona Province and the Gawler Craton ([Fig. 1c](#)) merits  
800 isotopic comparison between these terranes and with the North Australian Craton. Disperse U-Pb-Hf  
801 isotopic signatures from the detrital zircons in the Radium Creek Group supports a more complex  
802 provenance than from any one of the proximal magmatic suites (e.g. upper Gawler Range Volcanics,  
803 Frome Granite and Benagerie [Volcanics/Volcanic Suite](#)) analysed in this study ([Fig. 7e8c](#)).

804 The combined detrital zircon patterns of the Radium Creek Group strongly argue for provenance  
805 from a terrane that includes ca. 1595 Ma, ca. ~~1650~~[1660](#)-1680 Ma, ca. 1710-~~1760~~[1780](#) Ma, 1850 Ma  
806 and Earliest Palaeoproterozoic to Archaean magmatic rocks or significant inherited populations.  
807 Major magmatic events in eastern Early Mesoproterozoic Australia ca. 1595 Ma are also recorded in  
808 the Arunta Inlier with the ca. 1603-1615 Ma Burt-Rungtjirba Suite (Zhao and McCulloch, 1995; Zhao  
809 and Bennett, 1995), in the Musgrave Block with the Musgravian Gneiss (Gum and Belousova, 2006;  
810 Kirkland et al., In Press; Wade et al., 2006), and in the Curnamona Province with the ca. ~~1591-~~  
811 ~~1596~~[1600-1570](#) Ma Mundi Mundi, Cusin Creek plutons, Benagerie Volcanic Suite and Ninnerie  
812 Supersuite (Fanning et al., 1998; Jagodzinski and Fricke, 2010; Wade et al., ~~2012~~) ~~which was~~  
813 ~~accompanied by localised clastic deposition e.g. white sandstone in Bumarlow 1 drillhole (Fraser~~  
814 ~~and Neumann, 2011;2012), 2010~~). The Gawler Craton magmatism ca. 1604-1583 Ma is dominated by  
815 the voluminous felsic Gawler Range Volcanics and Hiltaba Suite (Fanning et al., 1988; Fanning et al.,  
816 2007) and localised deposition of clastic sediments (e.g. the upper Corunna Conglomerate) (Daly et  
817 al., 1998). Sedimentation in the Early Mesoproterozoic is also recorded across the North Australian  
818 Craton including the Upper McNamara Group in the Mount Isa Inlier (Andrews, 1998; Krassay et al.,

819 2000), the Favenc Package in the McArthur River area (Rawlings, 1999) and the Dargalong  
820 Metamorphics in the Georgetown Inlier (Withnall et al., 1997) (Fig. [41b](#)).

821 Palaeoproterozoic basin evolution is widespread and broadly comparable across eastern Australia  
822 characterised by the Leichhardt, Calvert and Isa Superbasins in the Mount Isa Inlier (Jackson et al.,  
823 2000), the Etheridge Group in the Georgetown Inlier (Withnall et al., 1988), Willyama Supergroup in  
824 the Curnamona Province (Conor and Preiss, 2008), and the metasediments preserved in the central  
825 and northern Gawler Craton (Hand et al., 2007; Payne et al., 2006; Szpunar et al., 2011). The basins  
826 in the Curnamona and Gawler Craton have been interpreted to have a predominantly evolved, felsic  
827 magmatic ca. 1710-~~1760~~[1780](#) Ma Arunta (Barovich and Hand, 2008; Payne et al., 2006) or northern  
828 Gawler Craton provenance (Howard et al., 2011c). Hf isotope datasets that include these 1710-  
829 [1760](#)~~1780~~ Ma metasediments and felsic intrusives from the [Fowler, Spencer, Olympic domains \(Fig.](#)  
830 [1c\) of the Gawler Craton \(Fig. 11a-b\)](#) (Belousova et al., ~~2006a; Belousova et al., 2009; Belousova et~~  
831 ~~al., 2006e2009~~; Howard et al., 2011a; Howard et al., 2011b; Howard et al., 2011c) (~~Fig. 7e; Szpunar~~  
832 ~~et al., 2011~~) closely correlate with the felsic derived 1710-~~1760~~[1780](#) Ma zircons in the Radium Creek  
833 Group. This would suggest that ca. 1710-~~1760~~[1780](#) Ma detrital zircons in the Radium Creek Group  
834 could have been sourced from felsic intrusives in the Gawler Craton (e.g. ca. 1736 Ma Middle Camp  
835 Granite and ca. 1755 Ma Wertigo Granite; Fanning et al. 2007; [see Fig. 1c](#)), re-worked ca. 1710-  
836 ~~1760~~[1780](#) Ma metasediments [\(e.g. Wallaroo Group and Moonabie Formation; see Fig. 1c\)](#) in the  
837 Gawler Craton, or from their protoliths in the northern Gawler Craton or Arunta Block.

838 However, potential ca. 1595 Ma felsic magmatic protoliths in the Arunta Block, [such as](#) the Burt-  
839 Rungtjirba Suite (Zhao, 1994) which has  $\epsilon\text{Nd}_{(1603-1615)}$  values of +0.91 to +2.49 is interpreted to be  
840 too juvenile to be a likely source of more evolved ca. 1595 Ma detritus in the Radium Creek Group.  
841 Moreover, comparison of the Hf isotopes of the Radium Creek Group detrital zircons with those of  
842 the Meso-Palaeoproterozoic Arunta Inlier (Hollis et al., 2010) shows little correlation between the  
843 disperse and generally negative, evolved ~~Hf~~ $\epsilon\text{Hf}_{(t)}$  in zircon characteristics ~~in~~of the Radium Creek  
844 Group (~~Fig. 7a-d~~) and the predominantly juvenile  $\epsilon\text{Hf}_{(t)}$  values for zircons from the Arunta region  
845 (~~Fig. 7h12a~~). This would imply that the direct ca. 1595 Ma source of the detritus in the Mount  
846 Painter Province is unlikely to be the Arunta Block but does not preclude the incorporation and  
847 assimilation of ca. 1710-1760 Ma Arunta derived material with more refractory Archaean to  
848 Palaeoproterozoic crust, in the potential source terrane for the Radium Creek Group.

849 Correlation of the Radium Creek Group with the available Hf isotopic datasets (modern drainage  
850 samples) for the Curnamona Province (Condie et al., 2005) ([Fig. 12b](#)) and Mount Isa Inlier (Griffin et  
851 al., 2006) (Fig. ~~7f~~[12c](#)) is plausible. The dataset for the [Broken Hill Block of the](#) Curnamona Province

852 however, does not include any analysis ~~on~~ of older Early Palaeoproterozoic or Archaean zircon grains-  
853 [\(Fig. 12b\)](#). A number of authors (e.g. Cooper, 1985; Page et al., 2005) have indicated the existence of  
854 ~~older~~ Archaean to Palaeoproterozoic zircon populations in the Curnamona Province, but further Hf  
855 isotope work is required to provide [robust](#) comparison with the pre-1700 Ma zircons in the Radium  
856 Creek Group. The Late Palaeoproterozoic to Early Mesoproterozoic zircon grains that constitute this  
857 Broken Hill dataset ([Fig. 7g12b](#)) are characterised by predominantly more juvenile Hf isotopic values  
858 than the Radium Creek Group. This more isotopically juvenile Hf range is consistent with the  
859 primitive  $\epsilon\text{Nd}_{(1650)}$  values of -3 to 0 reported by Barovich et al. (2008) for the upper Willyama  
860 Supergroup for which a distinct south-western Laurentia (Barovich et al., 2008) or [south](#)  
861 [west/southwest](#) Baltica (Howard et al. 2011a) provenance has been proposed.

862 The U-Pb ages and Hf isotopic compositions from Mount Isa Inlier (Griffin et al., 2006) and Mount  
863 Painter Province metasediments reflect both Archaean and Palaeoproterozoic phases of crustal  
864 reworking- [\(Fig. 11c\)](#). Mesoproterozoic magmatism in the Mount Isa Inlier did not initiate until ca.  
865 1550 Ma with the emplacement of the Williams and Naraku Batholiths (Page and Sun, 1998). It is  
866 therefore problematic to consider any major magmatic suites in the Mount Isa Inlier as the [likely](#)  
867 source of the dominant ca. 1595 Ma magmatic derived zircon population in the Radium Creek Group.

868 Instead, it is plausible that the ca. 1595 Ma zircons in the Radium Creek Group could have been  
869 derived from  $1595 \pm 6$  Ma,  $1589 \pm 3$  Ma minor tuffaceous horizons in the Lawn Hill Formation and  
870 Balbirini Dolomite [of the McArthur Basin](#) (Page et al., 2000). However they would most likely  
871 represent volumetrically insignificant contributions if the Mount Isa Inlier or McArthur [BlockBasin](#)  
872 were actively eroding ca. 1595 Ma and shedding material into the Mount Painter Province. The  
873 zircon budget from these tuffs would likely be swamped by competing sources.

874 ~~An increase in isotopically juvenile input ca. 1625 Ma in the Mount Isa dataset reflecting the~~  
875 ~~emplacement of the mafic Toole Creek Volcanics (Griffin et al., 2006) is similar to the increasingly~~  
876 ~~positive  $\epsilon\text{Hf}_{(t)}$  values in the Radium Creek Group ca. 1650-1680 Ma zircon population. In the Mount~~  
877 ~~Painter Province, this increase in more isotopically juvenile material reflects a more felsic magmatic~~  
878 ~~source based on the zircon geochemistry.~~ A paucity of isotopically juvenile felsic magmatism ca.  
879 ~~1650/1660~~-1680 Ma in eastern Proterozoic Australia [telescopes/reduces](#) potential source correlations  
880 for the Radium Creek Group. The ca. 1680 Ma felsic Tunkilla Suite in the Gawler Craton ([Fig. 1c](#))  
881 (Payne et al., 2010) which exhibits a large isotopic variation ( $\epsilon\text{Nd}_{(1680)}$  -6.3 to +2.6) is one possible  
882 exception. Erosion ca. 1595 Ma of a crustal pile that included this ca. 1680 Ma felsic material as well  
883 as more refractory Archaean to Palaeoproterozoic precursors is considered to be consistent with the  
884 isotopic fingerprint of the Radium Creek Group.

885 The ca. 1600-1540 Ma Musgravian Gneiss in the Musgrave Block, is characterised by juvenile Nd and  
886 Hf isotopic compositions ~~that are too juvenile~~ (Gum and Belousova, 2006; Kirkland et al., 2012;  
887 Wade et al., 2006) that are too juvenile to be considered as viable correlatives with the ca. 1595 Ma  
888 Radium Creek Group. Therefore, it is unlikely that the Radium Creek Group represents derivation  
889 from a proposed ca. 1600-1540 Ma magmatic arc in the Musgrave Block.

890 Correlation of the felsic magmatic-derived ca. 1850 Ma zircon grains in the Radium Creek Group is  
891 permissible with Hf datasets from the Gawler Hf dataset Olympic (Belousova et al., 2009) and  
892 Spencer domains (Szpunar et al., 2011) (Fig. 11a) of the Gawler Craton (Fig. 1c). These grains reflect  
893 the emplacement of the felsic Donington Suite (Fig. 1c) in the Gawler Craton (Drexel et al., 1995)  
894 which has  $\epsilon \text{Hf}_{(1850)}$  value range between ~~-3.53 and +4.3 (using the Lu-Hf decay constant of  $1.865 \times 10^{-11}$  yr<sup>-1</sup> (Scherer et al., 2001) for values from - and +5~~ (Reid et al., 2008; Szpunar et al., 2011). These data  
895 indicate both reworking of the ca. 2500 Ma material as well as some juvenile input ca. 1850 Ma.

897 These data are ~~not dissimilar from~~ similar to the ca. 1850 Ma Mount Isa Inlier Hf dataset (Fig. 12c)  
898 (Griffin et al., 2006) which corresponds to the emplacement of the ca. 1856 Ma Kalkadoon Batholith  
899 and co-magmatic Leichardt Volcanics (Page, 1983), and reflects remelting of Late Archaean material  
900 ca. 2500 Ma. The ca. 1850 Ma event in the Mount Isa Inlier does, however, comprise a far greater  
901 degree of mafic rocks with very positive  $\epsilon \text{Hf}_{(1850)}$  and are isotopically similar to the depleted mantle  
902 at ca. 1850 Ma. No such mafic (Fig. 9) and primitive isotopic signature (Fig. 8a,d) was  
903 ~~recorded~~ detected for zircons from the Radium Creek Group.

904 The Neoproterozoic to Earliest Palaeoproterozoic zircon grains in the Radium Creek Group return a  
905 broad range of  $\epsilon \text{Hf}_{(t)}$  values (-5.15 to +4.12), consistent with derivation from a complex Archaean  
906 source terrane that comprises both reworked and juvenile components. Whilst this is largely similar  
907 to the Archaean Mount Isa Inlier (Fig. 12c; Griffin et al., 2006) and Gawler datasets (~~Griffin et al.,~~  
908 ~~2006;~~ Belousova et al., ~~2006,~~ 2009; Howard et al., 2011a,b; 2011b), both the more evolved  $\epsilon \text{Hf}_{(t)}$   
909 values and > ca. 2600 Ma U-Pb populations evident in sample ARK661 (Elburg et al., 2012)), are more  
910 consistent with derivation from average Archaean Gawler Craton crust- (Fig. 11a-b). This  
911 ~~crust includes~~ crust includes the Meso-Neoproterozoic Middleback Group (Szpunar et al., 2011),  
912 preserved in Spencer and Cleve domains, granite gneisses (Fraser et al., 2010), and the Sleaford and  
913 Mulgathing complexes preserved in the Coult and Christie domains of the Gawler Craton (Fig. 1c)  
914 (Cowley and Fanning, 1992; Fanning, 1997; Schaefer, 1998; Swain et al., 2005a).

915 Collectively the detrital zircon isotopic pattern of the Radium Creek Group requires a complex source  
916 terrane. This source must include a significant felsic Early Mesoproterozoic portion as well as

917 Neoproterozoic to Palaeoproterozoic material that has undergone phases of Late Archaean to Early  
918 Mesoproterozoic re-working. This older material must itself have incorporated some juvenile  
919 components.

920 We consider the Gawler Craton to be the most plausible source for this composite signature of the  
921 ca. 1595 Ma Radium Creek Group. In this scenario, the Mount Painter Province is likely to be  
922 proximal to, and receiving material from, the eastern and central Gawler Craton at ca. 1595 Ma. The  
923 most probable source would be sub-aerial exposures of voluminous ca. 1595 Ma felsic material  
924 associated with the Gawler Range Volcanics ~~FHP~~[felsic large igneous province \(FLIP\)](#) (Pankhurst et al.,  
925 2013), particularly zircon grains derived from the Lower Gawler Range Volcanics. \_\_\_\_\_

#### 926 [4.6 Proterozoic tectonic implications](#)

927 Korsch et al. (2010) interpreted a distinctive seismic basement (termed the Warrakimbo Seismic  
928 Package) below the Mount Painter Province. We suggest that this basement is the eastern extension  
929 of the Gawler Craton and that the palaeo-Paralana Fault represents the eastern extent of the  
930 Gawler Craton. The palaeo-Paralana Fault is interpreted a moderately south-east-dipping, crustal-  
931 scale fault that separates the Warrakimbo and Yarramba seismic packages ([Korsch et al. 2010](#)),  
932 ~~suggesting that it represents~~[and has been interpreted as](#) a major crustal boundary- ([Korsch et al.](#)  
933 [2010](#)).

934 Since we now consider the Freeling Heights Quartzite and the Mount Adams Quartzite to be lateral  
935 equivalents and stitch the Paralana Fault, the age of the tectonic boundary (possibly a suture)  
936 between the Warrakimbo and Yarramba seismic packages must pre-date ca. 1595 Ma. ~~Given~~[Further](#),  
937 the isotopic and geochemical similarities between the Upper Gawler Range Volcanics and the  
938 Benagerie Volcanic Suite (Wade et al., 2012), ~~) suggests~~[the lower crust in the footwall of the palaeo-](#)  
939 [Paralana Fault may represent the same crustal sources \(e.g. Pankhurst et al., 2013\) of magmatism as](#)  
940 [the central Gawler Craton. The correlation of the upper Gawler Range Volcanics with the Benagerie](#)  
941 [Volcanics](#)~~Volcanic Suite~~ in the Curnamona Province ([Wade et al., \(2012\)](#) stitches the Gawler Craton  
942 and Curnamona Province together at ca. ~~1587 Ma, and may suggest that the Mount Painter Province~~  
943 ~~represents the eastern-most marginal terrane of the Gawler Craton prior to ca.~~ 1587 Ma.

944 ~~An~~[An](#) extensional event ca. 1595 Ma as suggested by Stewart and Betts (2010) is consistent with this  
945 scenario and supported by the interpretation by Korsch et al. (2010). In this scenario the Radium  
946 Creek Group was deposited within an extensional basin setting following the Olarian-Wartakan  
947 orogenic system- ([Page et al., 2005; Hand et al., 2007; Stewart and Betts, 2010](#)). This  
948 ~~extensional~~[tectonic](#) system could be quite far-reaching-~~to, and~~ include the Mount Woods Inlier and  
949 northern Gawler Craton (Cutts et al., 2011; Forbes et al., 2012) across southern Proterozoic Australia.

950 ~~Rapid switching from extension to shortening and back to extension during the ca. 1595-1585 Ma~~  
951 ~~interval suggests far field plate margin influences on the tectonics of the Mount Painter Province~~  
952 ~~(Armit et al. 2012). This extensional phase was followed by renewed crustal shortening and inversion~~  
953 ~~of the Radium Creek Metamorphics (Armit et al., 2012), and may have affected the northern Gawler~~  
954 ~~Craton (Kararan Orogeny; Hand et al., 2007), southern Curnamona Province (Rutherford et al., 2007),~~  
955 ~~and the Mount Isa Inlier (e.g., Betts et al., 2006). Repeated rapid switching from extension to~~  
956 ~~shortening at convergent plate margins is common during transient episodes of flat subduction~~  
957 ~~(Gutscher et al., 2002) or when subduction roll-back is interrupted by accretion of buoyant material~~  
958 ~~such as an ocean plateau (Rosenbaum et al., 2005; Mason et al., 2010), plume-head (Murphy et al.,~~  
959 ~~1998; Betts et al., 2009; 2012), arc terrane (Boutelier et al., 2003) or continental micro-continent~~  
960 ~~(Moresi et al., in review), which are all characterised by local trench advance and shortening in the~~  
961 ~~overriding plate. We propose that during the ca. 1595-1555 Ma interval, the Mount Painter Inlier~~  
962 ~~was located in the overriding plate of one or more subduction zones and was subjected to tectonic~~  
963 ~~mode switches caused by disruption of a convergent margin.~~

964 ~~The reconstructions of Betts & Giles (2006); Betts et al. (2002; 2009) and Wade et al. (2006) are~~  
965 ~~consistent with a proximal plate margin. However, the stitching of the Gawler Craton and the~~  
966 ~~Curnamona Province is inconsistent with the craton configuration of Wade et al. (2006). Data~~  
967 ~~presented here does not conclusively support or preclude configurations proposed by Betts & Giles~~  
968 ~~(2006); Betts et al. (2002; 2009); Cawood & Korsch (2008).~~

969  
970  
971  
972 ~~The palaeogeographic reconstructions of Betts & Giles (2006) (Fig. 2a); Betts et al. (2002; 2009),~~  
973 ~~Cawood and Korsch et al. (2008) and Wade et al. (2006) (Fig. 2b) are consistent the Mount Painter~~  
974 ~~Inlier being positioned proximal to one or more plate margins at ca. 1595 Ma. The configuration of~~  
975 ~~Wade et al. (2006) does not have the Gawler Craton and the Curnamona Province co-located~~  
976 ~~between ca. 1600-1580 Ma (Fig. 2b). The model of Wade et al. (2006) proposes that the Gawler~~  
977 ~~Craton was positioned in the overriding plate of the south-dipping subduction zone prior to collision~~  
978 ~~with the North Australian Craton at ca. 1590 Ma (Fig. 2b). In our reconstruction, the Curnamona~~  
979 ~~Province is also required to be co-located with the Gawler Craton and therefore must have evolved~~  
980 ~~in a back-arc setting on the overriding plate of a south dipping subduction zone and separated from~~  
981 ~~the Mount Isa Inlier before ca. 1580 Ma (Fig. 2b). In this model, the Radium Creek Group would~~  
982 ~~have been deposited in a back-arc setting and subsequent shortening resulted from collision~~  
983 ~~between North and South Australian cratons at ca. 1560 Ma. However, separation between the~~  
984 ~~North and South Australian cratons seems unlikely because of the well-established correlation of the~~

985 [ca.1720 to 1640 Ma basin systems between the Curnamona Province and North Australian Craton](#)  
986 [\(Giles et al., 2002; Page et al., 2005; Conor and Priess, 2008; Gibson et al., 2008\)](#). We therefore  
987 [consider a south-dipping subduction zone along the northern edge of the South Australian Craton](#)  
988 [highly unlikely at the beginning of the Mesoproterozoic.](#)

989 [The palaeogeographic reconstructions of Betts et al. \(2002\) and Betts and Giles \(2006\) consider that](#)  
990 [North and South Australian cratons to be contiguous at ca. 1600 Ma. The South Australian Craton](#)  
991 [was positioned between a long-lived accretionary convergent margin along the southern edge of the](#)  
992 [Australian continent \(Betts et al., 2011\), and a convergent margin along the eastern edge of the](#)  
993 [continent \(Betts et al., 2002\). Both these subduction zones are interpreted to dip towards the](#)  
994 [interior of the Australian continent \(Betts et al., 2009\). Superimposed on this complex tectonic](#)  
995 [setting is a major plume-related magmatic event \(Betts et al., 2007; 2009\). Tectonic interpretation of](#)  
996 [the evolution of the North Australian and South Australian cratons suggest that protracted episodes](#)  
997 [of high temperature metamorphism and continental basin systems formed in a back-arc setting](#)  
998 [\(Giles et al., 2002; Cutts et al., 2013\), which were interrupted by transient accretion events \(Betts et](#)  
999 [al., 2011\) at the plate margin. Betts et al., \(2009\) proposed that the Olarian-Wartaken orogenic](#)  
1000 [event was driven by the accretion of a plume-head with the Australian continent, which was](#)  
1001 [followed by an episode of crustal extension after the transfer of the plume to the overriding plate](#)  
1002 [\(see Betts et al., 2013\), producing a voluminous FLIP \(Pankhurst et al., 2013\) and a hotspot track](#)  
1003 [defined by dominantly A-type magmatism after ca. 1600 Ma \(Betts et al., 2007\). We suggest that](#)  
1004 [the deposition of the Radium Creek Group occurred in an extensional basin sourced from the FLIP](#)  
1005 [preserved on the Gawler Craton \(Fig. 13a\). The Radium Creek Group were buried to mid crustal](#)  
1006 [levels and then exhumed to the upper crust between ca. 1592 and ca. 1585 Ma requiring rapid](#)  
1007 [switches to crustal shortening \(Fig. 13b\) to renewed extension \(Armit et al., 2012\). This was followed](#)  
1008 [by renewed crustal shortening at ca. 1570-1555 Ma \(Rutherford et al., 2007; Armit et al., 2012\) \(Fig.](#)  
1009 [13c\). We interpret the tectonic switching is driven by perturbations in the convergent margin. We](#)  
1010 [are unable to assess the relative role of these convergent margins but may speculate that the earlier](#)  
1011 [shortening events \(ca. 1585 Ma\) is related to accretion along the southern margin of the continent](#)  
1012 [\(Fig.13a-b\), whereas ca. 1570-1555 Ma shortening is related to subduction along the eastern margin](#)  
1013 [of the continent \(Fig. 13c\).](#)

## 1014 **5 Conclusions**

- 1015 • The Radium Creek Group consists of a single stratigraphic package deposited in the Early  
1016 Mesoproterozoic with a maximum deposition  $^{207}\text{Pb}/^{206}\text{Pb}$  age of  $1595.5 \pm 3.7$  Ma (n=41).
- 1017 • ~~The detrital zircon patterns in the Radium Creek Group are characterised by peaks at ca.~~  
1018 ~~2500 Ma, ca. 1850 Ma, 1710-1760 Ma and 1650-1680 Ma. These are consistent with~~

1019 major zircon-forming episodes within the Gawler Craton (Belousova et al., 2009; Howard  
1020 et al., 2011a; Howard et al., 2011b; Reid et al., 2008; Swain et al., 2005b).

1021 • The isotopic fingerprint of the Radium Creek Group requires a source with diverse but  
1022 predominantly felsic character and evolved isotopic sources reflecting poly-phased crustal reworking  
1023 from the Archaean to the Early Mesoproterozoic. Detrital zircon patterns in the Radium Creek Group  
1024 that contains peaks at ca. 2500 Ma, ca. This fingerprint is most 1850 Ma, 1710-1780 Ma and 1660-  
1025 1680 Ma. These ages are consistent with derivation from the Gawler Craton as opposed to other  
1026 tectonic elements of eastern Proterozoic Australia, suggesting the Curnamona Province and Gawler  
1027 Craton were co-located at ca. 1595 Ma. The implication of this interpretation is that the North and  
1028 South Australian cratons were contiguous at ca. 1595 Ma placing the Mount Painter Inlier at the  
1029 nexus of two convergent margins characterised by subduction zones that dip towards the continent  
1030 interior. Perturbations in the dynamics of these convergent margins resulted in rapid tectonic  
1031 switches following deposition of the Radium Creek Group. Our data provides a critical constraint for  
1032 palaeogeographic reconstruction for eastern Australia at the Palaeo- to Mesoproterozoic transition.

1033 • ~~On the basis of its Early Mesoproterozoic Gawler provenance (this study),~~  
1034 ~~Mesoproterozoic architecture (Armit et al. 2012), and seismically distinctive basement~~  
1035 ~~(Korsch et al. 2010), we now consider the Mount Painter Province to be more consistent~~  
1036 ~~as an eastern marginal terrane of the Gawler Craton rather than as a north-eastern~~  
1037 ~~extension of the Curnamona Province.~~

1038

1039

1040

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1042

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1050 for their invaluable technical assistance. This work was supported in part by ARC LP0882000.

1051

## 1052 Figure Captions

1053

1054 ~~Fig. 1: Map highlighting the location of the Mount Painter Inlier~~  
1055 Fig. 1: a) Map of Australia showing  
1056 the geography-based nomenclature after Myer et al. (1996) in which the continent is divided into  
three major cratonic units, called the North, West and South Australian cratons draped over a

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1057 [composite of the bouguer gravity and first vertical derivative of the total magnetic intensity \(TMI\)](#)  
1058 [map of Australia \(geophysical data provided by Geoscience Australia\); b\) Map highlighting the](#)  
1059 [location of the Mount Painter Block](#) and other eastern Australian Proterozoic terranes in relation to  
1060 the major geological provinces of Australia. These are draped across a composite total magnetic  
1061 intensity (TMI) anomaly and first vertical derivative of the TMI map of Australia. This magnetic image  
1062 was produced using a two kilometre grid spacing and by applying a low pass filter (upward continued  
1063 six kilometres), which highlights the longer wavelengths/major structural elements of eastern  
1064 Australia. Data provided by Geoscience Australia.; c). [Map showing the position of the Mount](#)  
1065 [Painter Province \(grey box\) in respect to the major domains and Archaean to Mesoproterozoic](#)  
1066 [geology of the Curnamona Province after Conor and Preiss \(2008\) and the Gawler Craton modified](#)  
1067 [after Fairclough et al. \(2003\) and Hand et al. \(2007\).](#)

1068 [Fig. 2: a\) Palaeogeographical reconfiguration model after Giles et al. \(2004\); Betts and Giles](#)  
1069 [\(2006\) supporting a shared history for the South Australian Craton and the North Australian Craton](#)  
1070 [between ca. 1800 and 1550 Ma. This configuration aligns contemporaneous orogenic belts across](#)  
1071 [the Gawler Craton, Arunta Inlier, Mount Isa Inlier and the Curnamona Province.;](#) b)  
1072 [Palaeogeographical reconfiguration model after Wade et al. \(2006\) in which the Gawler Craton and](#)  
1073 [Curnamona Province are separated by a south-dipping subduction zone between ca.1600-1580 Ma](#)  
1074 [with the Gawler Craton positioned in the overriding plate.](#)

1075 [Fig. 3:](#) Map of the Mount Painter Inlier showing sample locations and regional geology after Armit et  
1076 al. (2012).

1077 [Fig. 34:](#) a) Photograph of the steeply dipping, foliated psammopelites of the Brindana Schist unit at  
1078 the base of Radium Creek Group, geo-pick shown for scale ([Samplesample Z3 363800E 6675681N](#));  
1079 b) Photo-micrograph of a thin section of ~~[Samplesample Z3 363800E 6675681N](#)~~ [from the Brindana Schist](#) in cross-  
1080 polarised light ~~([363800E 6675681N](#))~~ [from the Brindana Schist](#), cut normal to the  $S_3$  foliation. This  
1081 view demonstrates overprinting, spaced foliations defined by muscovite  $\pm$  biotite fabrics (sub-  
1082 horizontal in photo-micrograph) and recrystallised polygonal quartz aggregate (microlithons); c)  
1083 Photograph of the intensely crenulated, micaceous quartzite outcrop of the Freeling Heights  
1084 Quartzite ([Samplesample F 357632E 6673138N](#)); d) Photo-micrograph of a thin section of the  
1085 Freeling Heights Quartzite in cross-polarised light ~~([Sample F 357632E 6673138N](#))~~. The section, taken  
1086 normal to the  $S_3$  foliation, highlights a spaced schistosity defined by muscovite with elongate relic  
1087 quartz grains which display undulose extinction. A discrete crenulation cleavage overprints the  
1088 existing schistosity; e) Photograph of quartzite ~~unit of unit of~~ the Freeling Heights Quartzite  
1089 ([Samplesample 123 355996E, 6672099N](#)). Cross-beds defined by heavy ~~mineral assemblages~~ [minerals](#)  
1090 and distinct compositional layering (compare with bottom right of picture) record reverse grading.  
1091 This indicates that younging is upwards and towards the west (head of the geo-pick is orientated E-  
1092 W); f) Photo-micrograph of [Samplesample 123](#) in cross-polarised light ~~([355996E, 6672099N](#))~~. The  
1093 section was cut normal to the  $S_3$  foliation and highlights two spaced and overprinting foliations  
1094 defined by biotite  $\pm$  muscovite and polygonal quartz-rich microlithons; g) Photograph of the fine-  
1095 grained pinky-grey micaceous quartzite outcrop of the Mount Adams Quartzite (Sample 36;  
1096 357161E, 6668472N). Cross beds defined by heavy ~~mineral assemblages~~ [minerals](#) indicate upward  
1097 younging; h) Photo-micrograph of [Samplesample 36](#) in cross-polarised light shows fine grained  
1098 muscovite, sercite and quartz-rich assemblage. A sub-horizontal spaced foliation, defined by fine-  
1099 grained micaceous material, overprints an earlier mica fabric with polygonal undulose quartz and

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1100 biotite microlithons; i) Photograph of a hand specimen from the Pondanna member of the upper  
1101 Gawler Range Volcanics (573593E, 6405524N) showing porphyritic texture with phenocrysts of  
1102 quartz and feldspar within a dark, aphanitic groundmass; j) Photo-micrograph of Sample YD23a from  
1103 the Pondanna member of the upper Gawler Range Volcanics (573593E, 6405524N), section shows  
1104 phenocrysts of k-feldspar, quartz, and ~~clinopyroxene~~eproxene within a fine grained matrix .

1105 Fig. 45: Cathodoluminescence and ~~Backback~~ scatter electron images ~~(a-d & e-j respectively of~~  
1106 ~~example~~representative zircon grains from each sample analysed in this study. The region ablated  
1107 during analysis is indicated; a) ~~Cathodoluminescence image of~~ Z1-29a,b zircon grains from sample Z3  
1108 (Brindana Schist). Z1-29a grain has a U-Pb age  $1659 \pm 15$  Ma and an  $\epsilon_{\text{Hf}}$  value of +5.80, Z1-29b grain  
1109 has a U-Pb age of  $1604 \pm 16$  Ma and a  $\epsilon_{\text{Hf}}$  value of -6.1; b) ~~Cathodoluminescence image of~~ Z3-24  
1110 zircon grain from sample Z3 (Brindana Schist). This grain has a U-Pb age of  $2369 \pm 28$  Ma and an  $\epsilon_{\text{Hf}}$   
1111 value of -4.89; c) ~~Cathodoluminescence image of~~ F6 zircon grain from sample F (Freeling Heights  
1112 Quartzite). This grain has a U-Pb age of  $1670 \pm 10$  Ma and an  $\epsilon_{\text{Hf}}$  value of +0.01; d)  
1113 ~~Cathodoluminescence image of~~ F9 zircon grain from sample F (Freeling Heights Quartzite). This grain  
1114 has a U-Pb age of  $2539 \pm 28$  Ma and an  $\epsilon_{\text{Hf}}$  value of +1.29; e) ~~Back scatter electron image of~~ 36-13  
1115 zircon grain from sample 36 (Mount Adams Quartzite). This grain has a U-Pb age of  $1596 \pm 8$  Ma and  
1116 an  $\epsilon_{\text{Hf}}$  value of -1.79; f) Back scatter electron image of 36-10 zircon grain from sample 36 (Mount  
1117 Adams Quartzite). This grain has a U-Pb age of  $1678 \pm 29$  Ma and an  $\epsilon_{\text{Hf}}$  value of -1.64; g) ~~Back~~  
1118 ~~scatter electron image of~~ 123-17 zircon grain from sample 123 (Freeling Heights Quartzite). This  
1119 ~~grain has grain has~~ a U-Pb age of  $1589 \pm 9$  Ma; h) ~~Back scatter electron image of~~ 123-1 zircon grain  
1120 from sample 123 (Freeling Heights Quartzite). This grain has a U-Pb age of  $1712 \pm 8$  Ma; i) ~~Back~~  
1121 ~~scatter electron image of~~ YD23a-7 zircon grain from sample YD23a (uGRV). This grain has a U-Pb age  
1122 of  $1596.2 \pm 36$  Ma and an  $\epsilon_{\text{Hf}}$  value of -2.74; j) ~~Back scatter electron image of~~ YD23a-27 zircon grain  
1123 from sample YD23a (uGRV). This grain has a U-Pb age of  $1597.6 \pm 47$  Ma and ~~ana~~  $\epsilon_{\text{Hf}}$  value of -4.5.

1124 Fig. 56: a) Probability plot of detrital zircons analysed from sample Z3. Inset: weighted mean  
1125  $^{207}\text{Pb}/^{206}\text{Pb}$  ( $2\sigma$ ) age plot for the youngest population in this sample, interpreted as the maximum  
1126 depositional age.; b) Concordia plot for zircons analysed from sample Z3 ;c) Probability plot of  
1127 detrital zircons analysed from sample F. Inset: weighted mean  $^{207}\text{Pb}/^{206}\text{Pb}$  ( $2\sigma$ ) age plot for the  
1128 maximum depositional age of this sample; c) ~~Zircons~~Zircon grains from sample F plotted on a U-Pb  
1129 concordia plot; d) ~~Concordia plot for zircons analysed from sample F;~~ e) Detrital zircon probability  
1130 plot from sample 123. Inset: weighted mean age  $^{207}\text{Pb}/^{206}\text{Pb}$  ages ( $2\sigma$ ) for the maximum depositional  
1131 age ; ef) Concordia diagram for zircons analysed from sample 123; fg) Probability plots for zircon  
1132 analysed from sample 36. Inset: weighted mean  $^{207}\text{Pb}/^{206}\text{Pb}$  ages ( $2\sigma$ ) for the maximum depositional  
1133 age for this sample; gh) U-Pb concordia plot for ~~zircon~~zircon analysed from sample 36.

1134 Fig. 6-7: Weighted mean  $^{207}\text{Pb}/^{206}\text{Pb}$  ages plot for sample YD23a showing the dominant population  
1135 and older inherited grains. Inset: Tera-Wasserburg concordia plot shows the concordant (<10%  
1136 discordant) analyses, as well as all data >10% discordant from this sample. Data error ellipses and  
1137 error bars used are  $1\sigma$ .

1138 Fig. 7-Plots8: a) Plot of  $\epsilon_{\text{Hf}(t)}$  versus  $^{207}\text{Pb}/^{206}\text{Pb}$  ages for the Radium Creek Group samples; b) Plot of  
1139  $T_{\text{DM}}^{\text{c}}$  versus  $^{207}\text{Pb}/^{206}\text{Pb}$  ages for the Radium Creek Group samples; c) Plot of  $\epsilon_{\text{Hf}(t)}$  versus  $^{207}\text{Pb}/^{206}\text{Pb}$   
1140 ages for the Radium Creek Group samples including values for ARK661 sample from Elburg et al.  
1141 (2012). Fields compared with the values for the upper Gawler (Belousova et al. 2009), Isa (Griffin et  
1142 al. 2006), Broken Hill (Condie et al. 2005) Range Volcanics, uGRV from the Gawler Craton (sample  
1143 YD23a), and Arunta (Hollis et al. 2010) terranes are the Frome Granite of the Bimbowrie Suite  
1144 (sample FG12) and Benagerie Volcanic Suite (sample BV) from the Curnamona Province (see Fig. 1c-d  
1145 for sample locations). Inset shows a plot of  $T_{\text{DM}}^{\text{c}}$  versus  $^{207}\text{Pb}/^{206}\text{Pb}$  ages for these samples; d) Field  
1146 for the Radium Creek Group  $\epsilon_{\text{Hf}(t)}$  values plotted as gridded density and data points for comparison.  
1147 ~~All U-Pb dates shown as  $^{207}\text{Pb}/^{206}\text{Pb}$  ages, Hf isotope values recalculated using a decay constant of~~

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1148 ~~1.865E10<sup>±4</sup>yr~~ Density grids for the Radium Creek Group, Gawler, Isa and Broken Hill are grid  
1149 constructed using cell size of 20 Myrs/Myr in the X direction and 0.5 ε Hf units in the Y direction, a  
1150 threshold level of 0.05 and a smoothing level of 3.

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1151 Fig. 89: Comparison of zircon crystallisation rock type, modelled from in-situ trace chemistry after  
1152 Belousova et al. (2002) to determine the source rock type of zircon grains across the Paralana Fault.  
1153 Sample F (357632E 6673138N) is from the Freeling Heights Quartzite to the west (Hangingwall) of  
1154 the Paralana Fault. Sample 36 (357161E, 6668472N) is from the Mount Adams Quartzite to the east  
1155 (Footwall) of the Paralana Fault. The modelled source rock type is predominantly felsic and  
1156 indistinguishable across the Paralana Fault.

1157 Fig. 910: Stratigraphic and structural framework of the Mount Painter Inlier using data from this  
1158 study and Armit et al. (2012). Proterozoic magmatic ages determined using U-Pb geochronology by  
1159 LA-ICPMS and SHRIMP where available. Mount Neill Granite and porphyry age from Teale (1987,  
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1166 et al. (2000, 2005), Rutherford et al. (2007), Marjoribanks et al. (1980) and Clarke et al. (1987, 1995).  
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1180 Fig. 11: a) Plot of ε Hf<sub>(t)</sub> versus <sup>207</sup>Pb/<sup>206</sup>Pb ages for Archaean to Mesoproterozoic zircon populations  
1181 for the major domains of the Gawler Craton from Belousova et al. (2009); Howard et al.  
1182 (2009;2010;2011a;2011b); Szpunar et al. (2011), compared with the samples from the Radium Creek  
1183 Group (this study); b) Field for the Gawler Craton ε Hf<sub>(t)</sub> values from Belousova et al. (2009); Howard  
1184 et al. (2009;2010;2011a;b); Szpunar et al. (2011) plotted as gridded density and data points for  
1185 comparison with the samples from the Radium Creek Group plotted as points. Density grid  
1186 constructed using cell size of 20 Myr in the X direction and 0.5 ε Hf units in the Y direction, a  
1187 threshold level of 0.05 and a smoothing level of 3.

1188 Fig. 12: a) Plot of ε Hf<sub>(t)</sub> versus <sup>207</sup>Pb/<sup>206</sup>Pb ages for Archaean to Mesoproterozoic zircon populations  
1189 from the Arunta Block (Hollis et al. 2010) displayed as a gridded density field compared with the  
1190 samples from the Radium Creek Group shown as points; b) Plot of ε Hf<sub>(t)</sub> versus <sup>207</sup>Pb/<sup>206</sup>Pb ages for  
1191 Archaean to Mesoproterozoic zircon populations from the Broken Hill Block of the Curnamona  
1192 Province (Condie et al. 2005) displayed as a gridded density field, compared with the samples from  
1193 the Radium Creek Group shown as points; c) Plot of ε Hf<sub>(t)</sub> versus <sup>207</sup>Pb/<sup>206</sup>Pb ages for Archaean to  
1194 Mesoproterozoic zircon populations from the Broken Hill Block of the Mount Isa Inlier (Griffin et al.  
1195 2006) displayed as a gridded density field compared with the samples from the Radium Creek Group

1196 [shown as points. All U-Pb dates shown as  \$^{207}\text{Pb}/^{206}\text{Pb}\$  ages, Hf isotope values recalculated using a](#)  
1197 [decay constant of  \$1.865\text{E}10^{-11}/\text{yr}\$ .](#) [Table 4](#) [Density grids for the Radium Creek Group, Gawler Craton,](#)  
1198 [Curnamona Province and Mount Isa Inlier are constructed using cell size of 20 Myrs in the X direction](#)  
1199 [and 0.5  \$\epsilon\$  Hf units in the Y direction, a threshold level of 0.05 and a smoothing level of 3.](#)

1200  
1201 [Fig 13: a\) Palaeogeographical reconstruction of eastern Proterozoic Australia at ca. 1595 Ma adapted](#)  
1202 [after Giles et al. \(2004\); Betts and Giles \(2006\); Betts et al. \(2006;2007;2009\). In this model the](#)  
1203 [Radium Creek Group are deposited in an extensional back-arc basin and sourced from the Felsic](#)  
1204 [large igneous province \(FLIP\) preserved on the Gawler Craton; b\) Rapid tectonic switching to](#)  
1205 [shortening ca. 1585 Ma and back to extension is driven by perturbations in the convergent margins](#)  
1206 [along the southern margin of Australia; c\) Renewed crustal shortening at ca. 1555 Ma is related to](#)  
1207 [subduction along the eastern margin of the continent.](#)

1208  
1209 [Table 1: Lu-Hf values for standards run to determine instrumentation precision and accuracy.](#)

1210 [Table 2: U-Pb values for standards run during the study acquisition period and longer-term averages](#)  
1211 [indicating the level of reproducibility and instrument stability obtained.](#)

1212 [Table 2: Lu Hf values for standards run for to determine instrumentation precision and accuracy.](#)

1213 Table 3: Summary of the U-Pb dating and Hf isotope analysis.

1214 Table 4: [Modelled Zircon crystallisation rock type, modelled](#) rock type from in-situ trace element  
1215 [chemistry- after Belousova et al. \(2002\).](#)

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1617

Table 1

Analysis No.	$^{176}\text{Lu}/^{177}\text{Hf}$	$^{176}\text{Yb}/^{177}\text{Hf}$
91500-263	0.00031	0.010689
91500-10-28	0.000334	0.015847
91500-10-28	0.000334	0.015847
91500-262	0.000312	0.011659
<b>91500 average</b>	0.000322	0.01351
MT8	0.000129	0.006351
MT3	0.000061	0.002555
MT-10-141	0.000023	0.001197
MT-10-147	0.000023	0.001014
MT9	0.000151	0.006771
MT2	0.000141	0.006
MT4	0.000114	0.004514
MT-10-1045	0.000058	0.002614
MT-10-1046	0.000134	0.007539
MT-10-1047	0.000134	0.007145
MT-10-746	0.000128	0.00598
MT-10-745	0.000119	0.005629
MT-10-727	0.000102	0.005138
MT-10-744	0.000149	0.008101
<b>Mudtank average</b>	0.000105	0.005039

Table 2

Sample	Method	$^{207}\text{Pb}/^{206}\text{Pb}$	$\pm 2 \sigma$
<b>Mud Tank</b> <sup>a)</sup>	TIMS		
Jackson et al. 2004 (73 values) <sup>b)</sup>	LAM-ICPMS	736	7
This study (17 values)	LAM-ICPMS	749	13
<b>91500</b> <sup>c)</sup>	TIMS	1065.4	0.3
Jackson et al. 2004 (83 values) <sup>b)</sup>	LAM-ICPMS	1068	6
This study (18 values)	LAM-ICPMS	1072	12
This study (5 values)	LAM-ICPMS	1067	17

Weighted mean ages in Ma and reported with  $2 \sigma$  error.

<sup>a)</sup>Mud Tank TIMS age from Black and Gulson (1978).

<sup>b)</sup>Long term ages from LAM-ICPMS at GEMOC (Jackson et al., 2004).

<sup>c)</sup>91500 TIMS age from Wiedenbeck et al. (1995).

Table 3

Sample	$^{207}\text{Pb}/^{206}\text{Pb}$ population	Age type	$\epsilon\text{Hf}_{(t)}$ range
Z3	ca. 1595 Ma	Max dep	-6.7 to +2.77
Z3	1630-1690 Ma	Detrital population	-4.21 to +5.8
Z3	1710-1760 Ma	Detrital population	-6.58 to +2.74
Z3	1790-1850 Ma	Detrital population	-4.9 to -2.89
Z3	2300-2500 Ma	Detrital population	-4.89 to -1.11
Z3	ca. 2900 Ma	Detrital population	+7.27
F	ca. 1595 Ma	Max dep	-6.11 to +2.44
F	ca. 1680 Ma	Detrital population	-9.91 to 0
F	ca. 1730 Ma	Detrital population	-9.4 to -0.53
F	ca. 1841 Ma	Detrital population	-2.56
F	ca. 2500 Ma	Detrital population	-5.15 to +1.29
36	ca. 1595 Ma	Max dep	-5.37 to +2.79
36	ca. 1680 Ma	Detrital population	-3.82 to -1.07
36	1710-1740 Ma	Detrital population	-3.63 to -2.07
36	ca. 1850 Ma	Detrital population	-6.32 to -3.24
36	ca. 2500 Ma	Detrital population	-2.77 to -0.93
36	ca. 2948 Ma	Detrital population	-9.46
<b>RCG grouped</b>			
	ca. 1595 Ma	Max dep	-6.7 to +2.79
	ca. 1660-1680 Ma	Detrital population	-9.91 to +5.8
	ca. 1710-1780 Ma	Detrital population	-9.4 to +2.74
	ca. 1850 Ma	Detrital population	-6.32 to -2.56
	ca. 2500 Ma	Detrital population	-5.15 to +1.29
YD23a	ca. 1595 Ma	Crystallisation	-4.51 to +3.01
YD23a	ca. 1680 Ma	Inherited	-1.14 to -0.98
YD23a	ca. 1760 Ma	Inherited	+1.61 to +2.43
YD23a	ca. 1793 Ma	Inherited	+2.73
YD23a	ca. 1955 Ma	Inherited	+2.81
FG12	ca. 1557 Ma	?	+5.96
FG12	ca. 1594 Ma	Crystallisation	-5.29 to +1.02
FG12	ca. 1640 Ma	Inherited	-2.7
BV	ca. 1587 Ma	Crystallisation	-1.73 to +4.0

**Table 4**

Analysis No.	$^{207}\text{Pb}/^{206}\text{Pb}$ age (Ma)	$\varepsilon_{\text{Hf}(t)}$	Lu (ppm)	Hf (wt%)
<b>Freeling Heights Quartzite</b>				
F217	1596	2.440156	52.7089	1.148022
F218	1571	-7.83882	73.74621	1.089765
F5	1652	-9.90644	91.14652	1.284635
F6	1670	0.002682	96.96011	1.212131
F212	1679	-0.57732	114.0913	1.004032
F7	1703	-5.12109	41.04014	1.258517
F220	1717	-6.0367	75.11273	0.863858
F213	1727	-9.48304	110.8835	1.178974
F4	1732	-4.64357	42.17228	0.886923
F214	1736	-5.67648	152.9471	1.179822
F219	1739	-5.77617	70.22908	1.107149
F2	1743	-0.52651	168.4766	1.214675
F223	1755	-7.28026	86.62932	1.06424
F215	1841	-2.5559	86.25845	1.515122
F8	2532	-5.15289	57.69946	1.242744
F9	2539	1.294357	87.61727	1.105029
<b>Mount Adams Quartzite</b>				
36_10	1678	-1.64	97.6505	1.014038
36_11	1873	-6.32115	121.7584	1.17643
36_35	2948	-9.45523	115.2526	0.906342
36_13	1596	-1.79517	69.46603	1.056693
36_12	1624	-5.37101	80.68111	1.180331
36_15	2466	3.401276	102.6962	1.37571
36_16	1680	-3.8181	90.38005	0.970706
36_17	1671	-1.07311	111.0748	1.677768
36_18	1711	-3.3586	96.14368	0.983765
36_14	1714	-3.42383	122.0813	1.106979
36_2	2519	-2.7661	143.2733	1.416838
36_6	2479	-0.93406	91.94859	1.283618
36_19	1697	-2.06505	146.4794	1.243507
36_7	1739	-3.62661	137.8884	1.155739
36_20R	1585	0.906116	101.2873	1.483322
36_3	1575	2.791108	96.43351	1.211707
36_4	1850	-3.23558	59.27636	1.049909
36_5	1586	-1.36469	221.7525	1.266997

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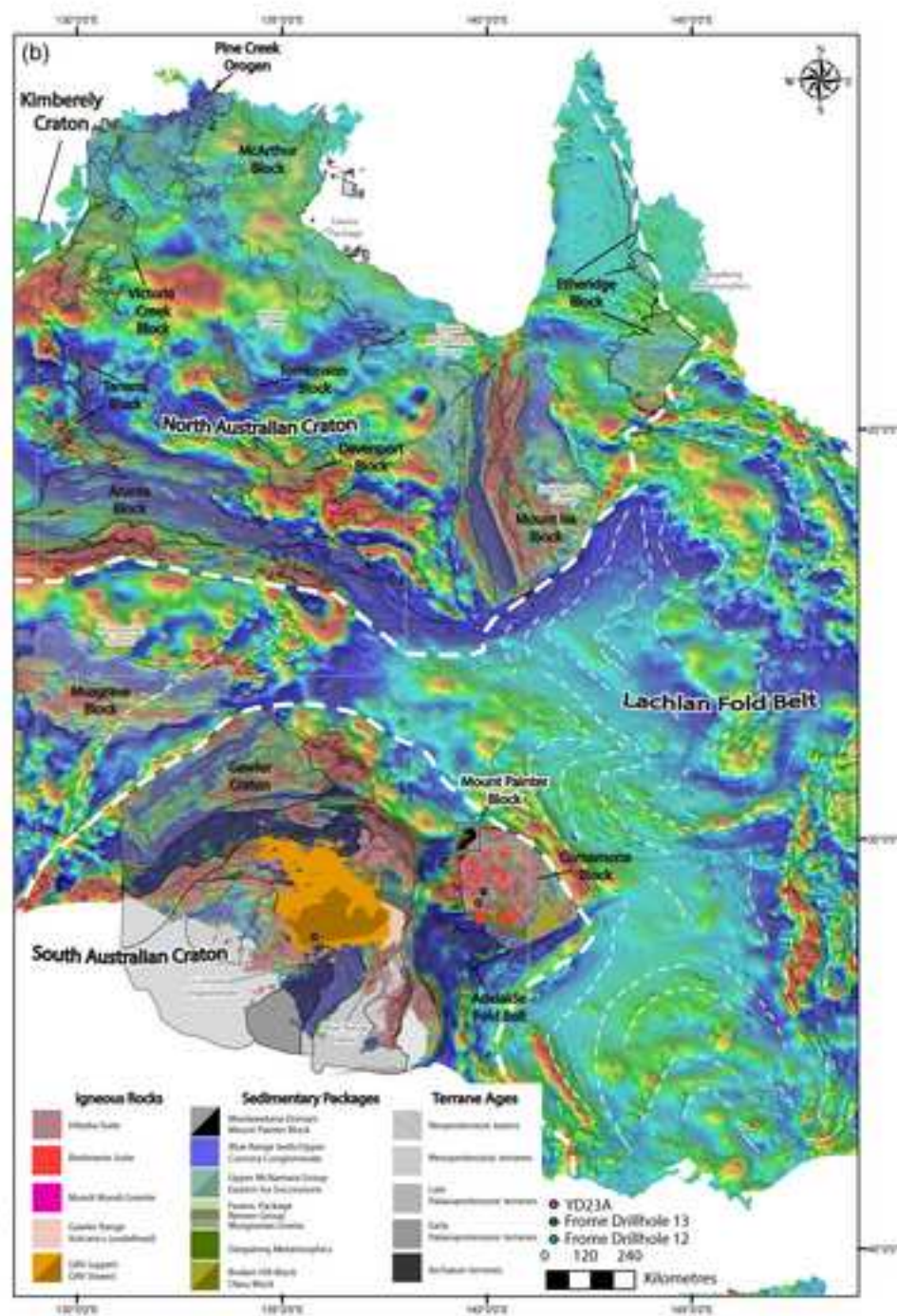
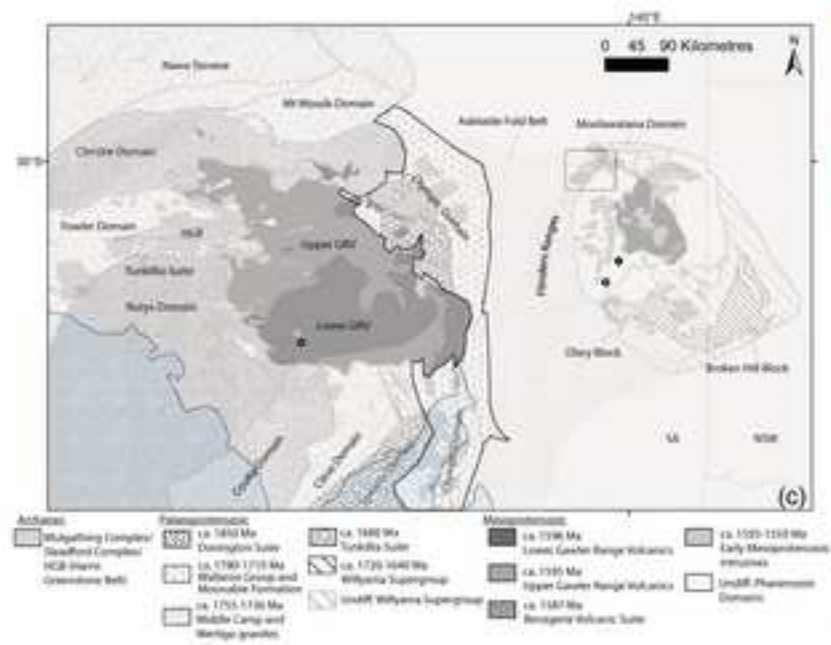
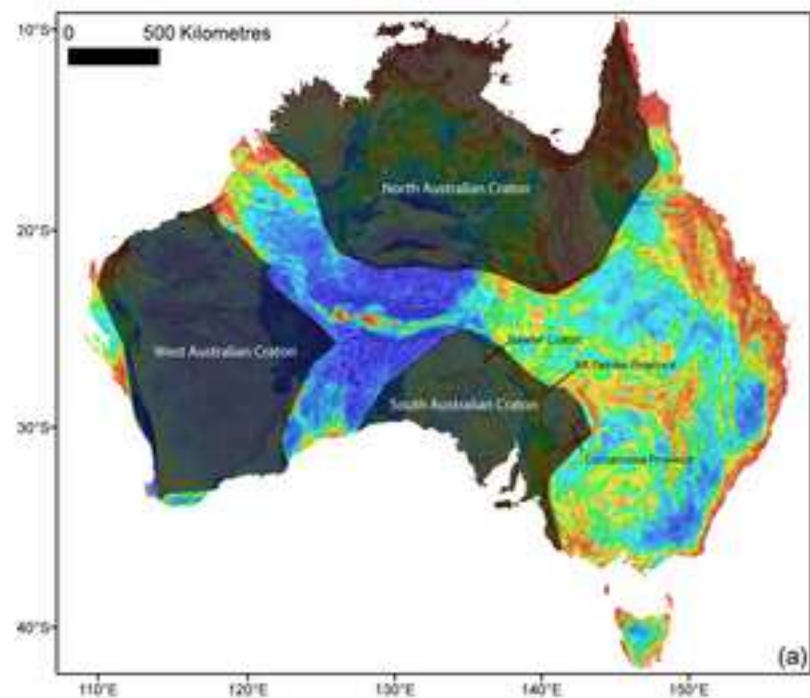


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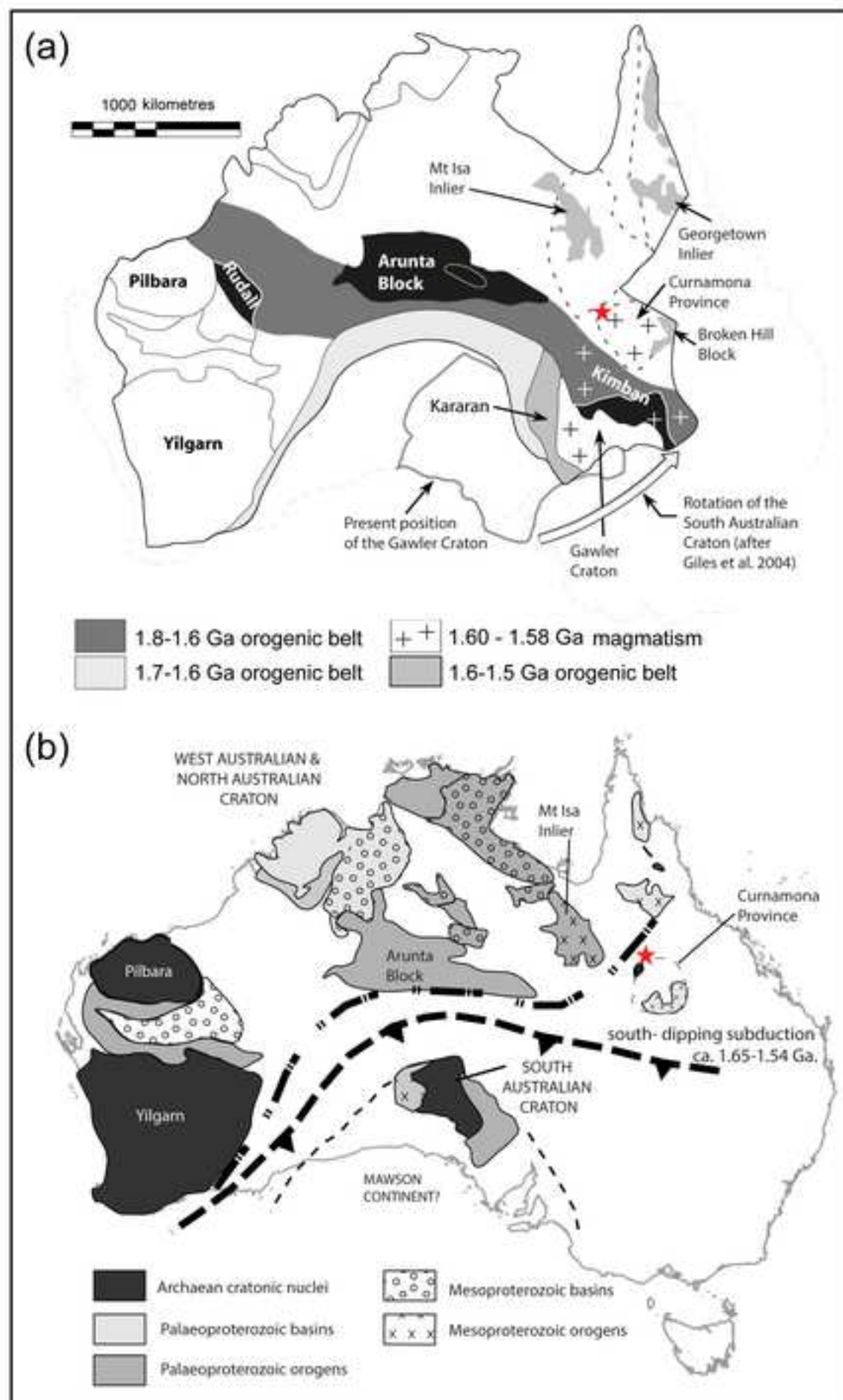


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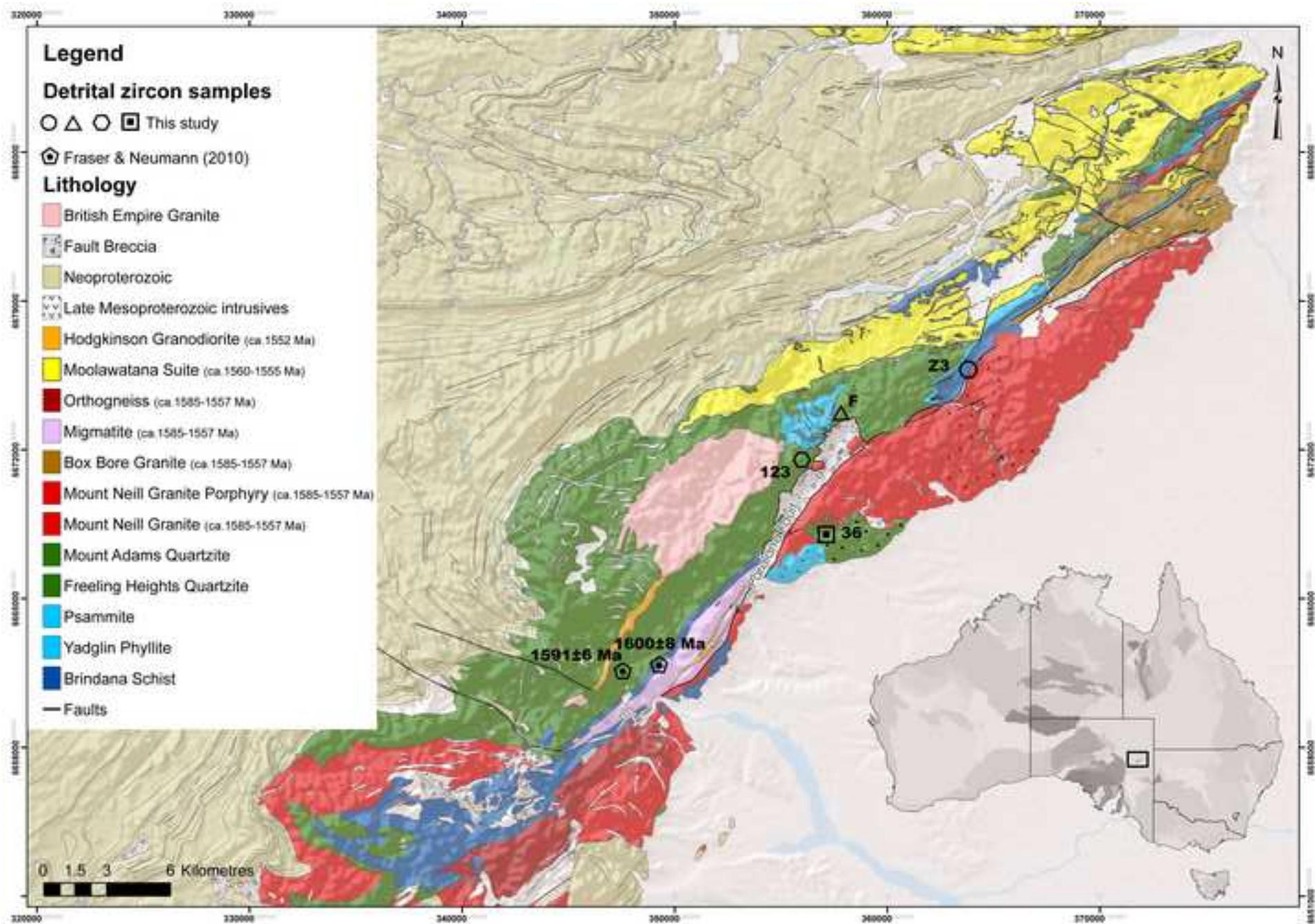


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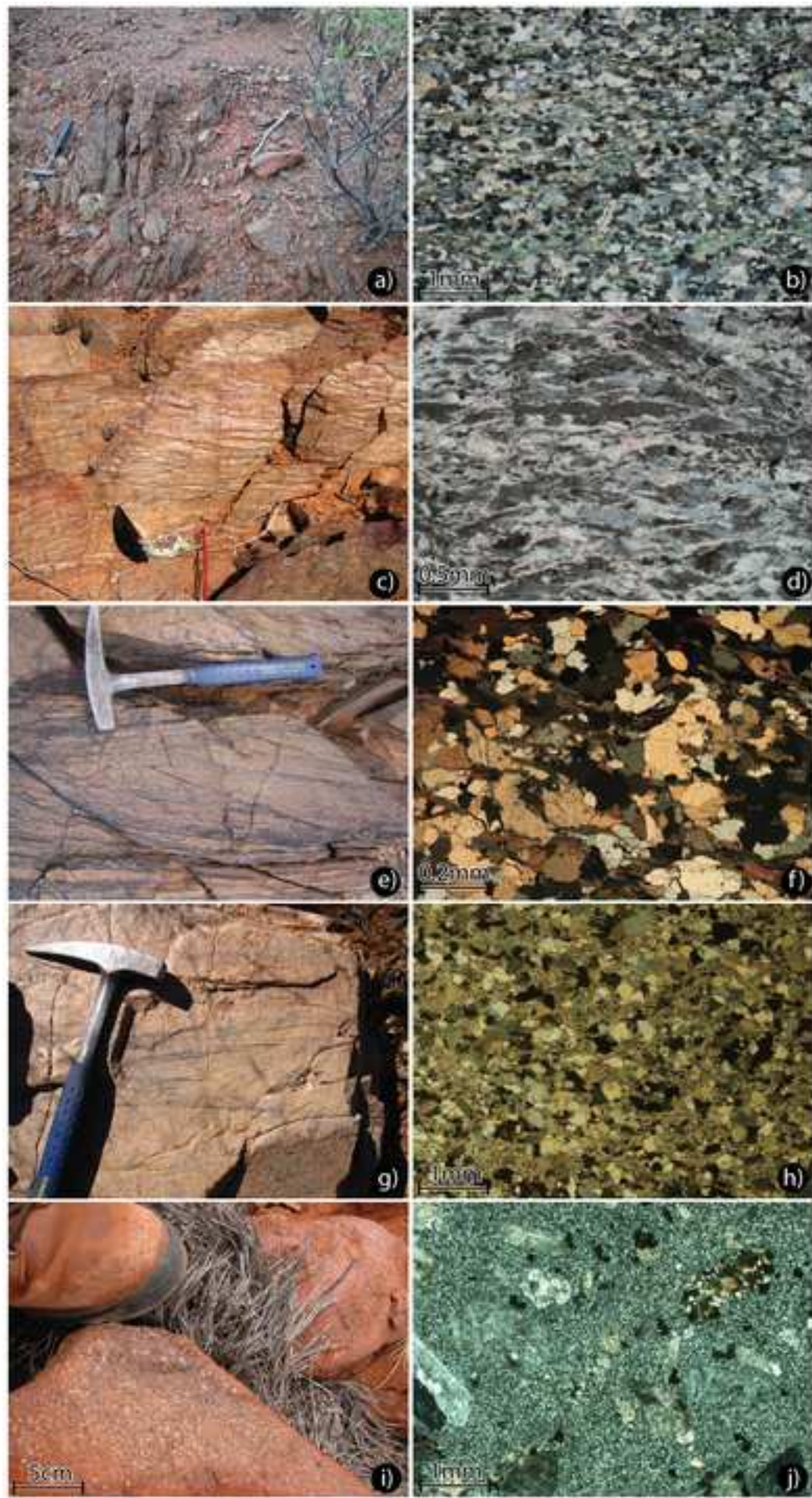


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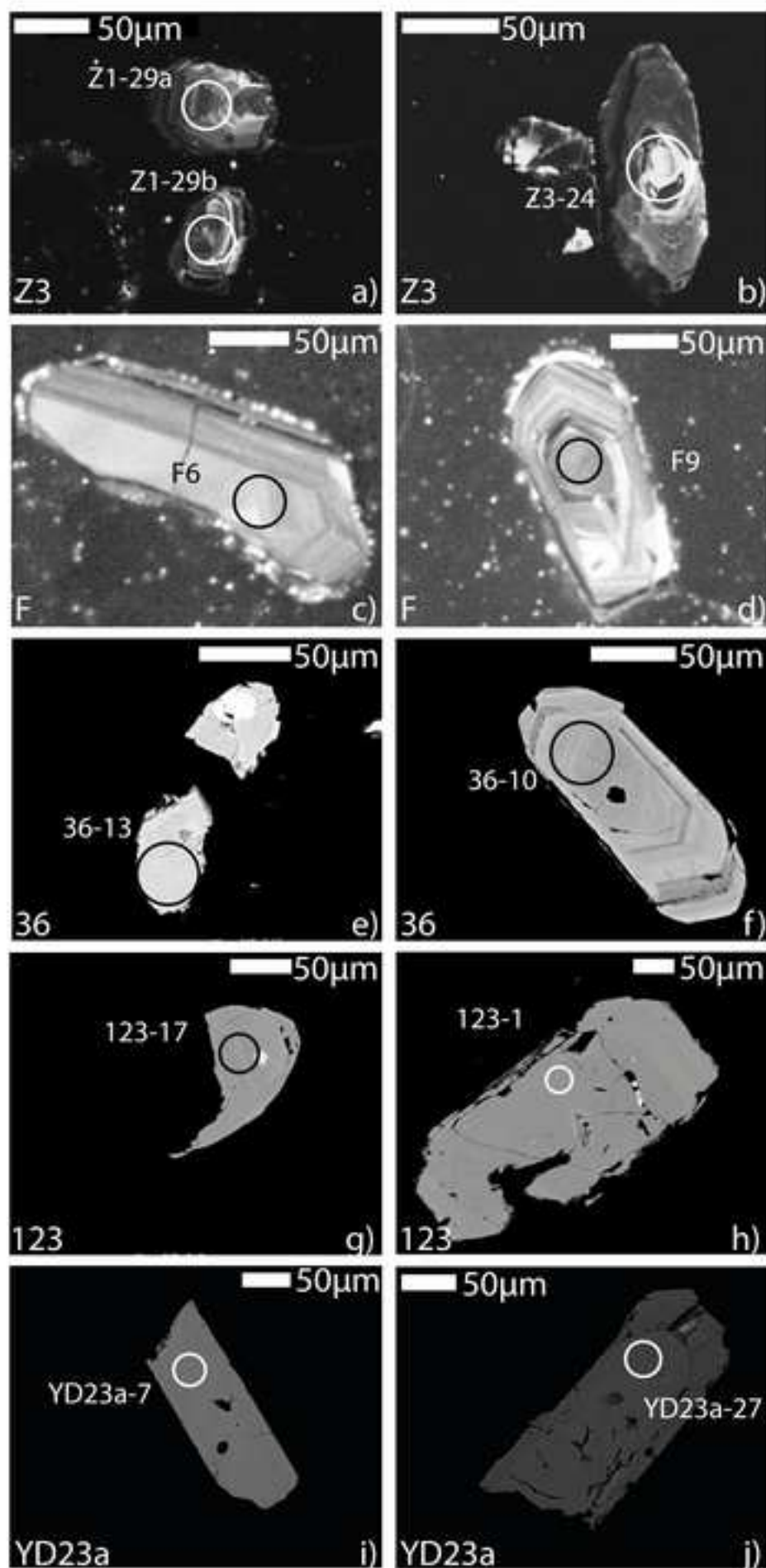


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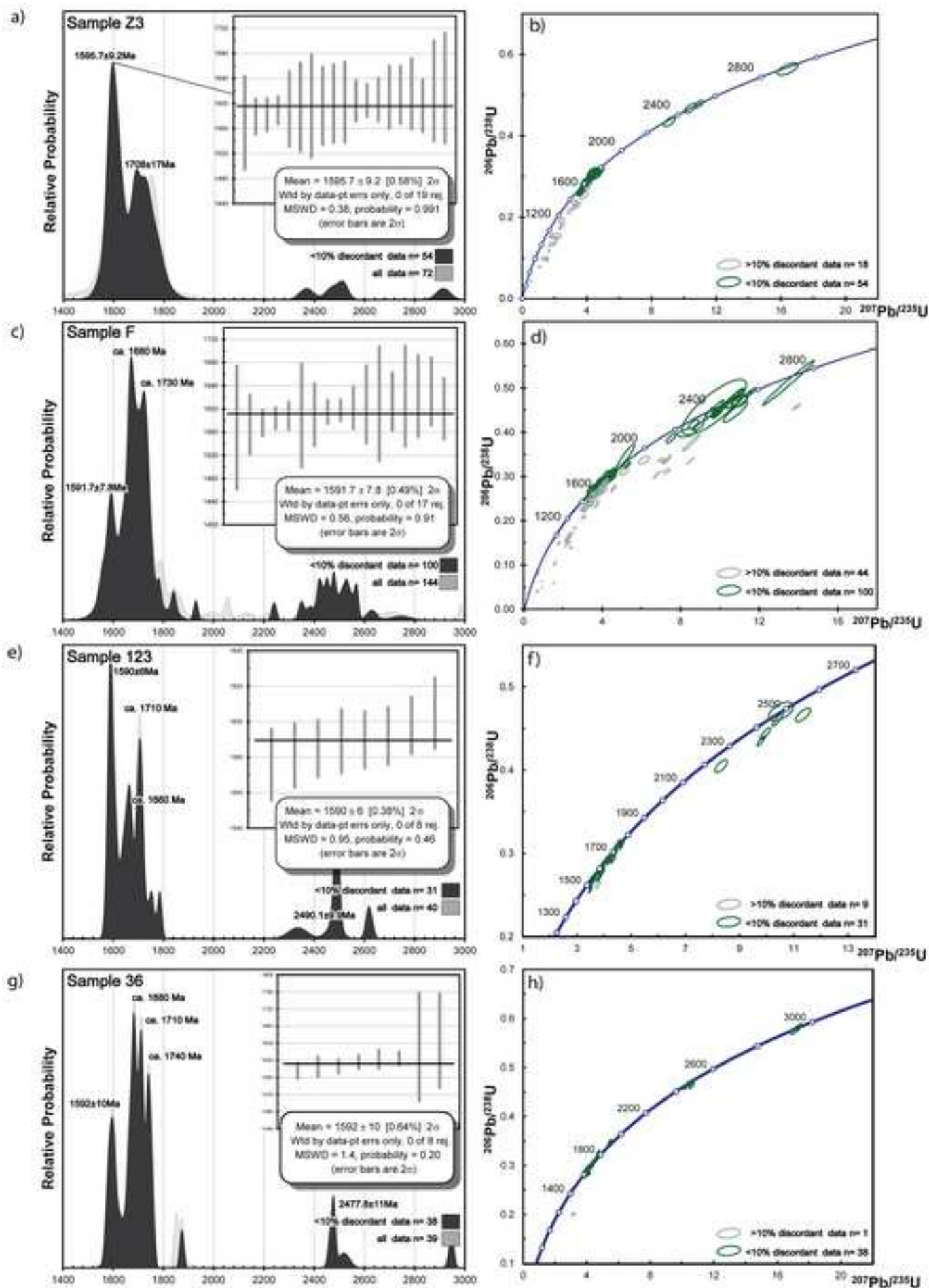


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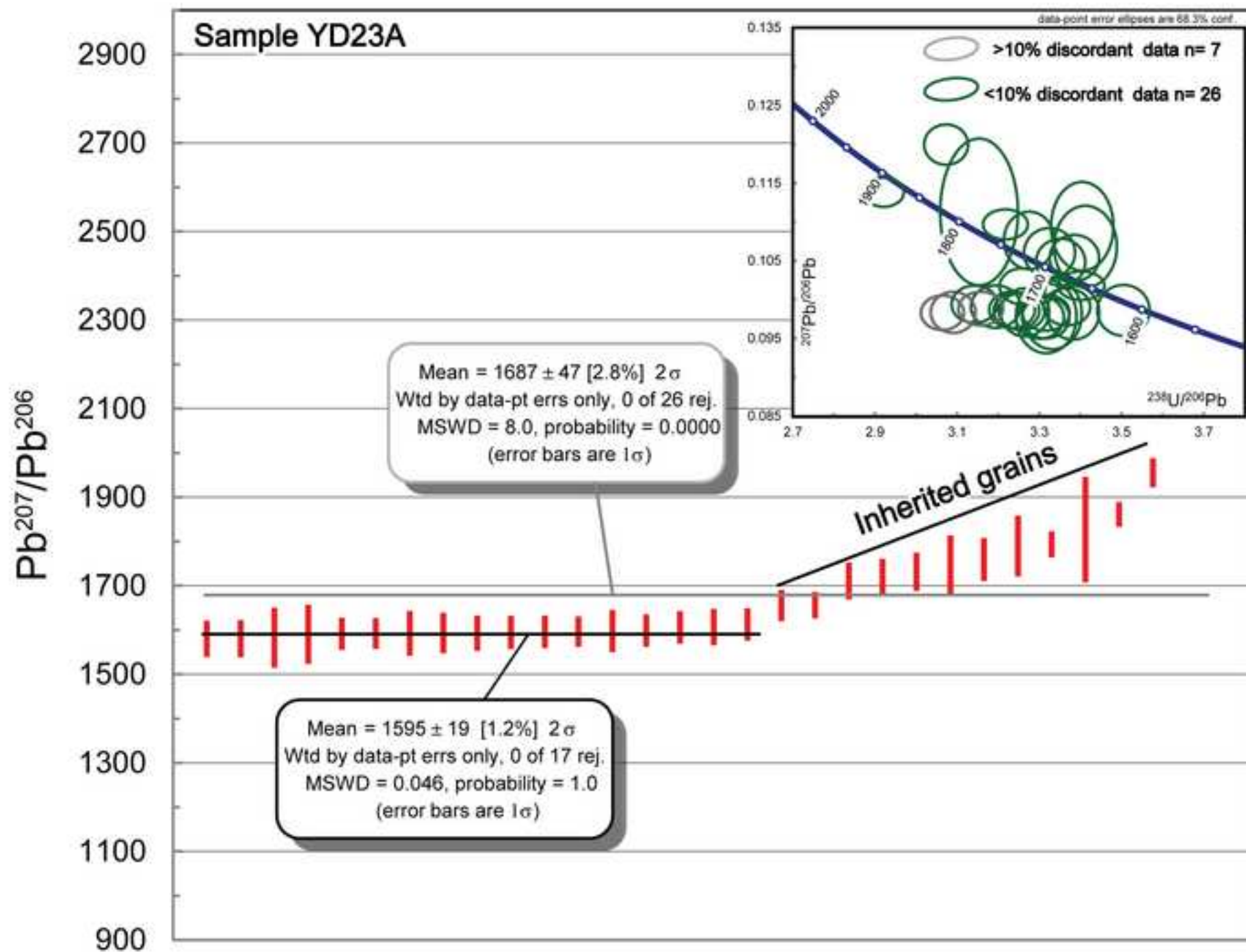


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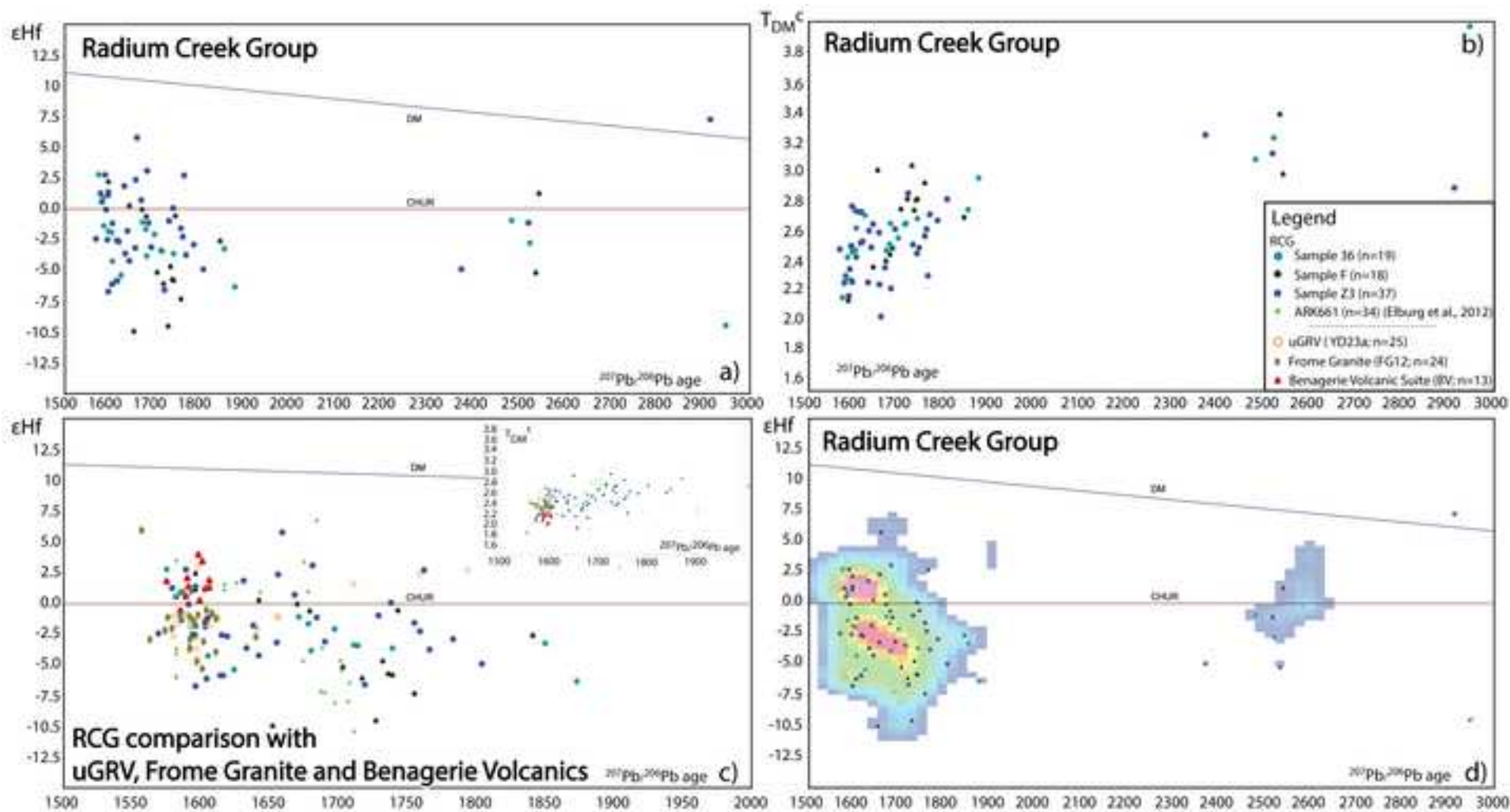
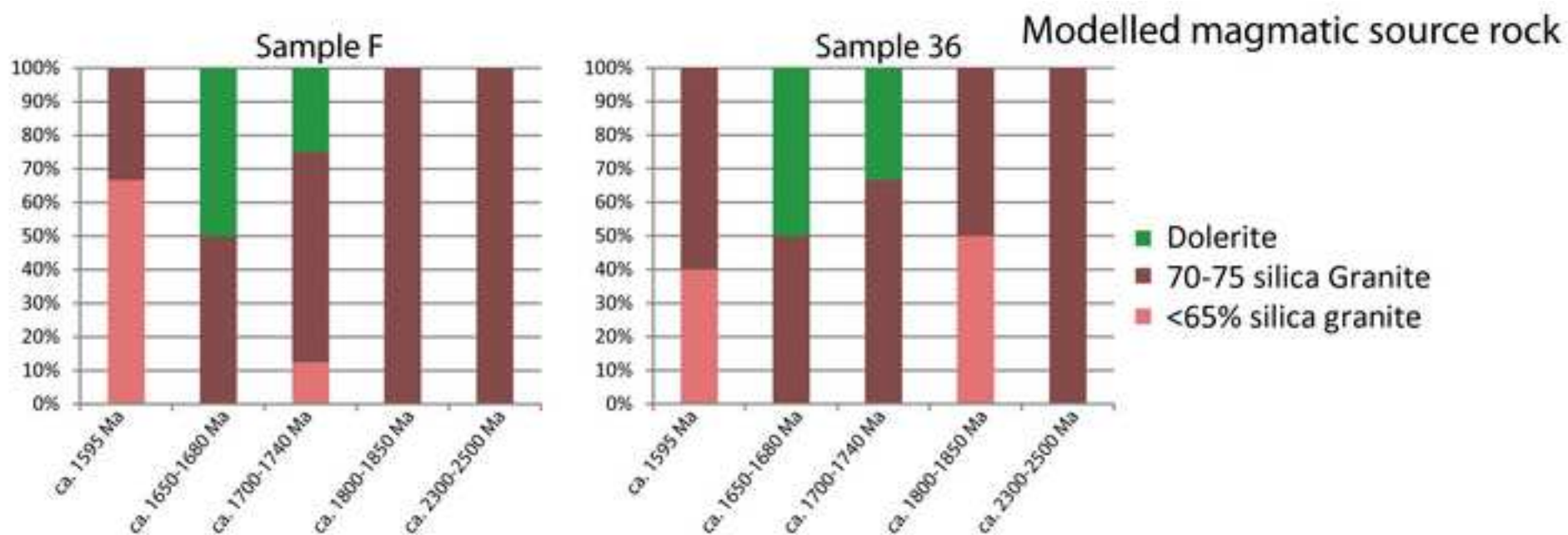


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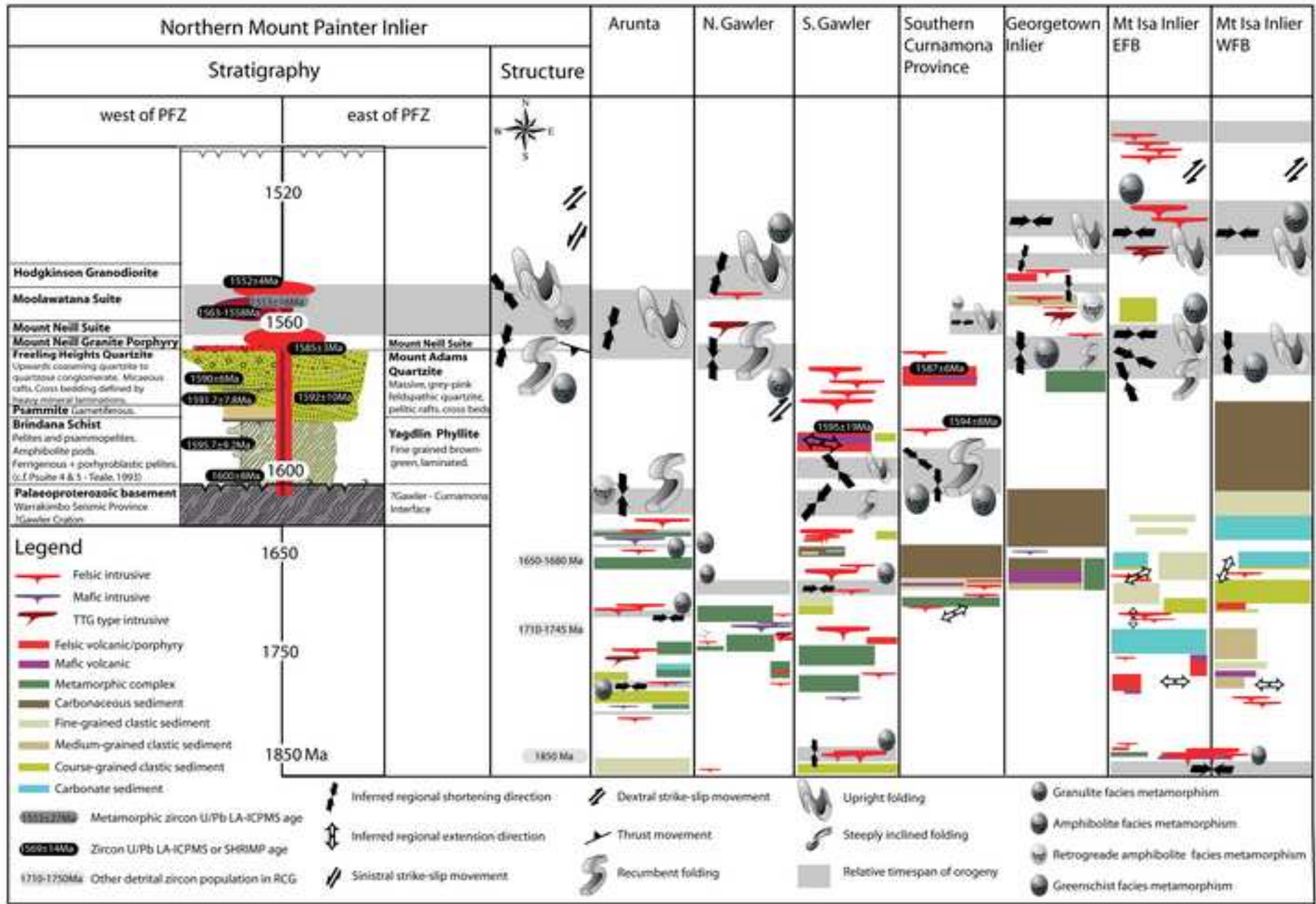


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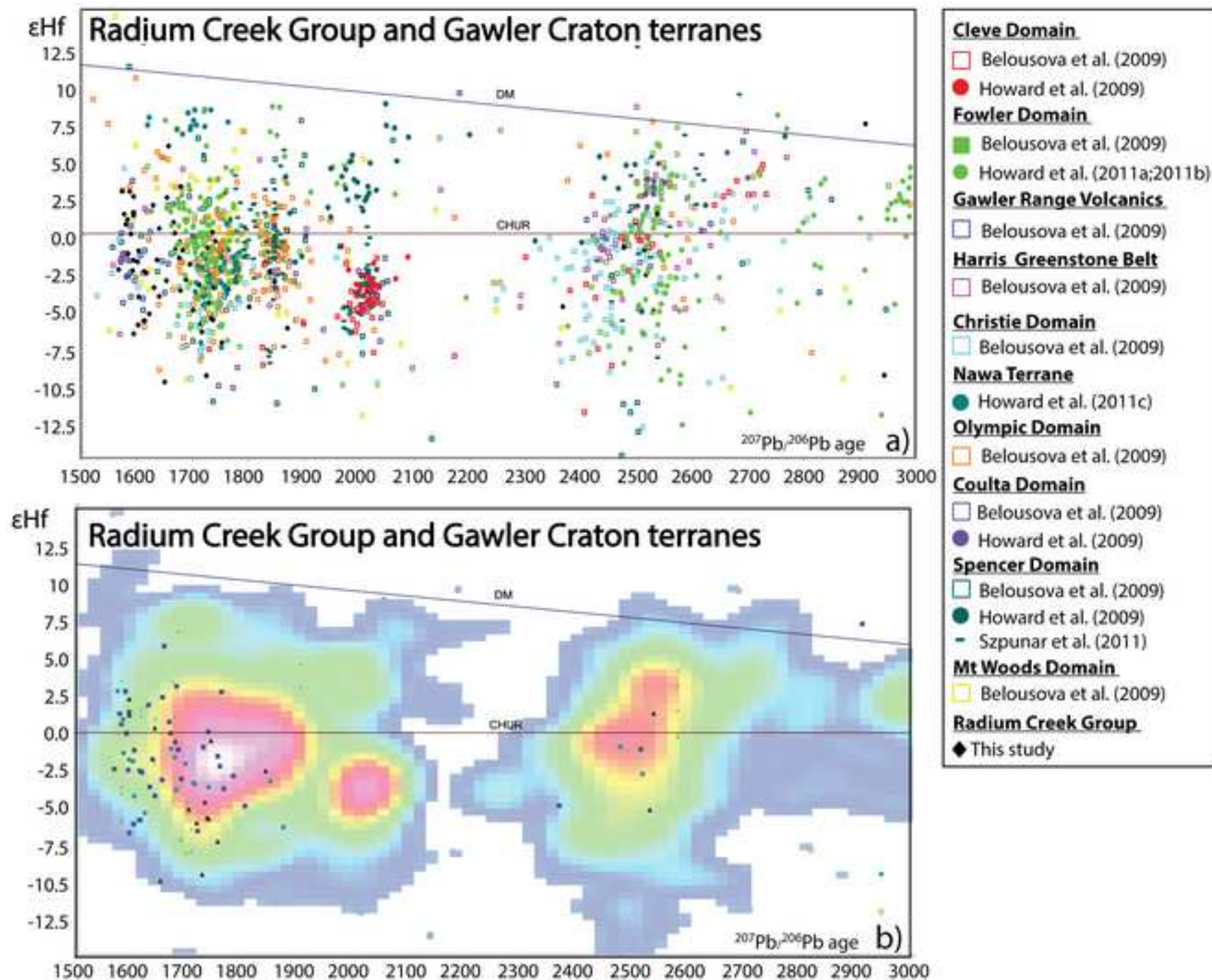
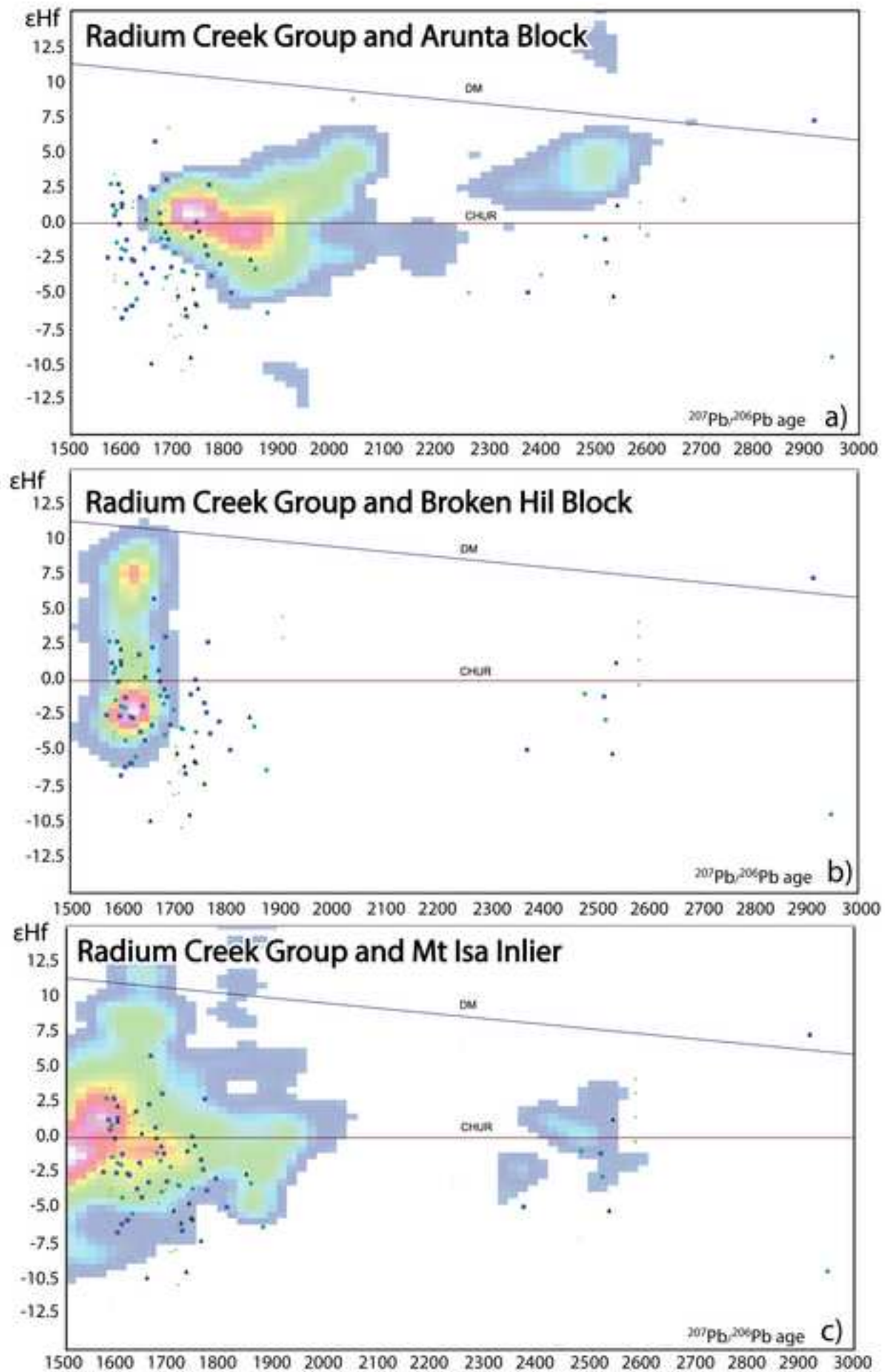


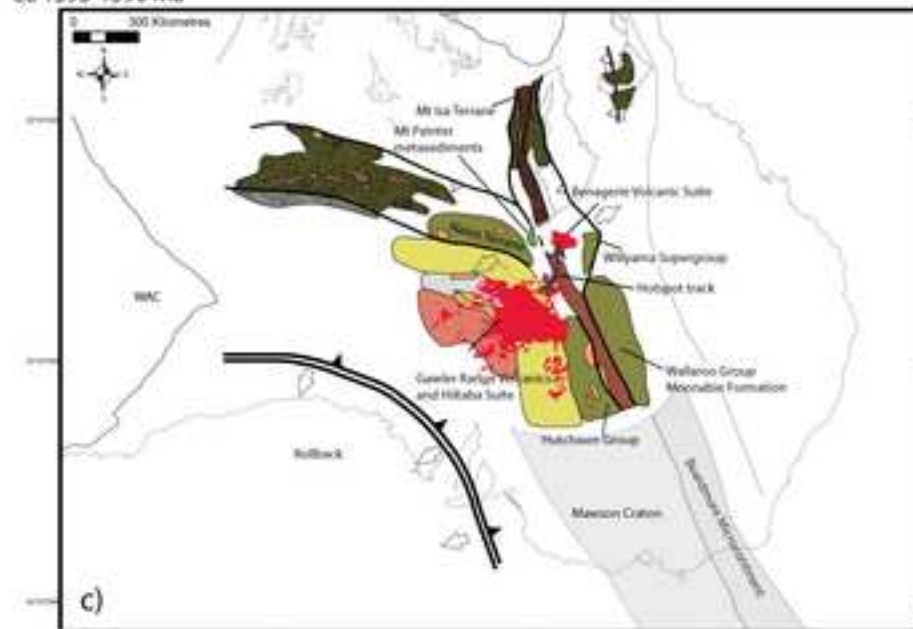
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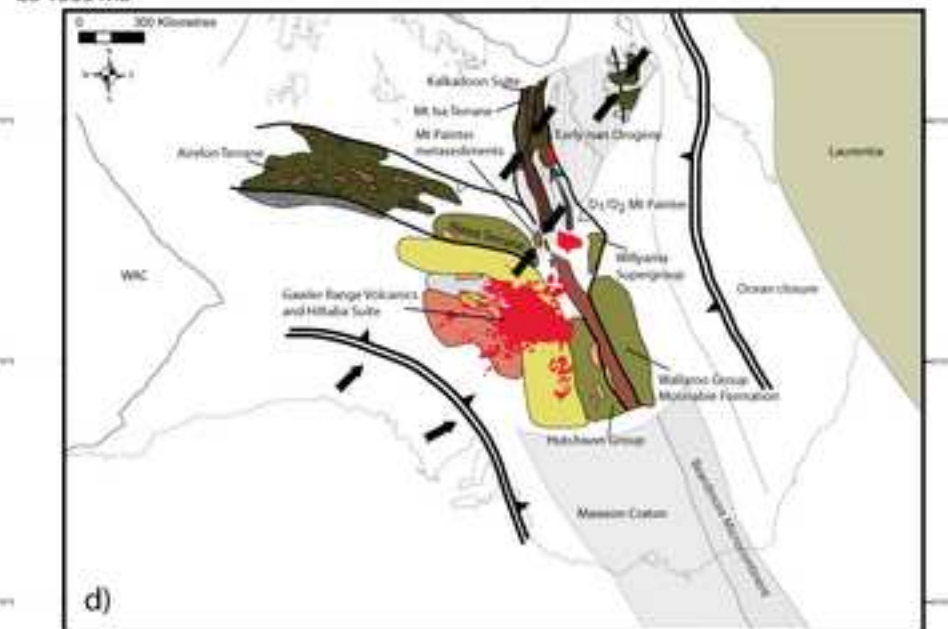


**Figure 13**  
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Ca 1595-1590 Ma



Ca 1585 Ma



Ca 1555 Ma

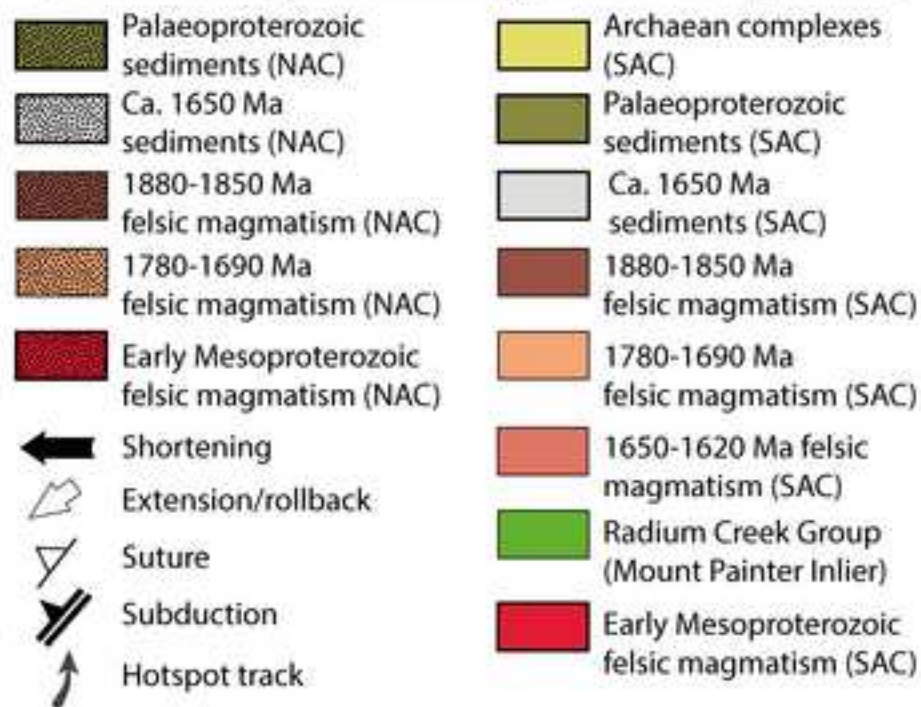
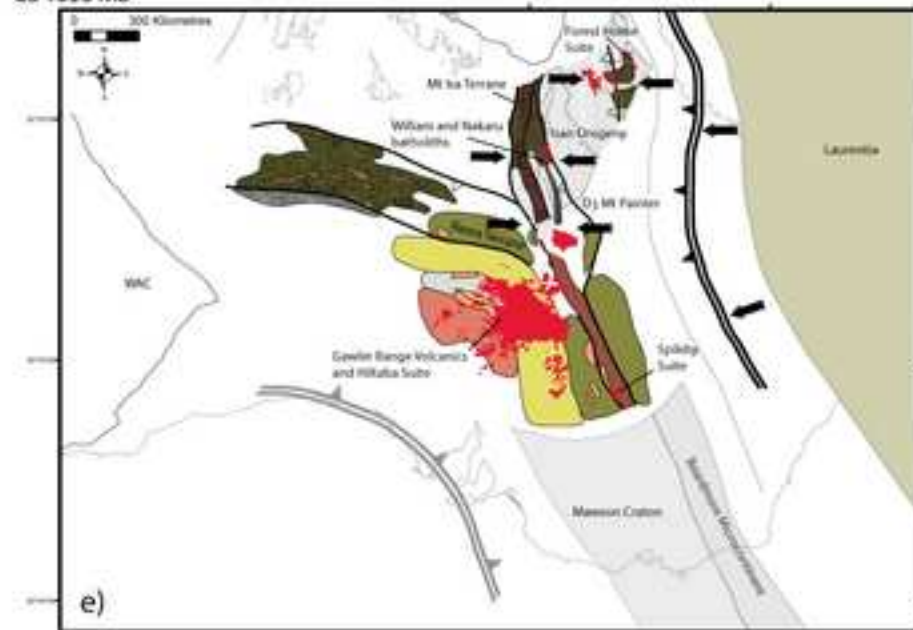


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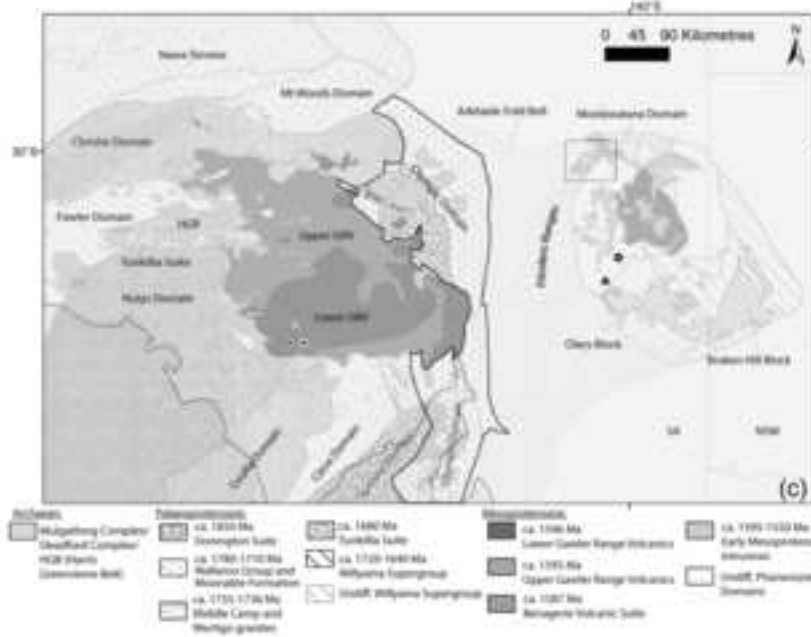
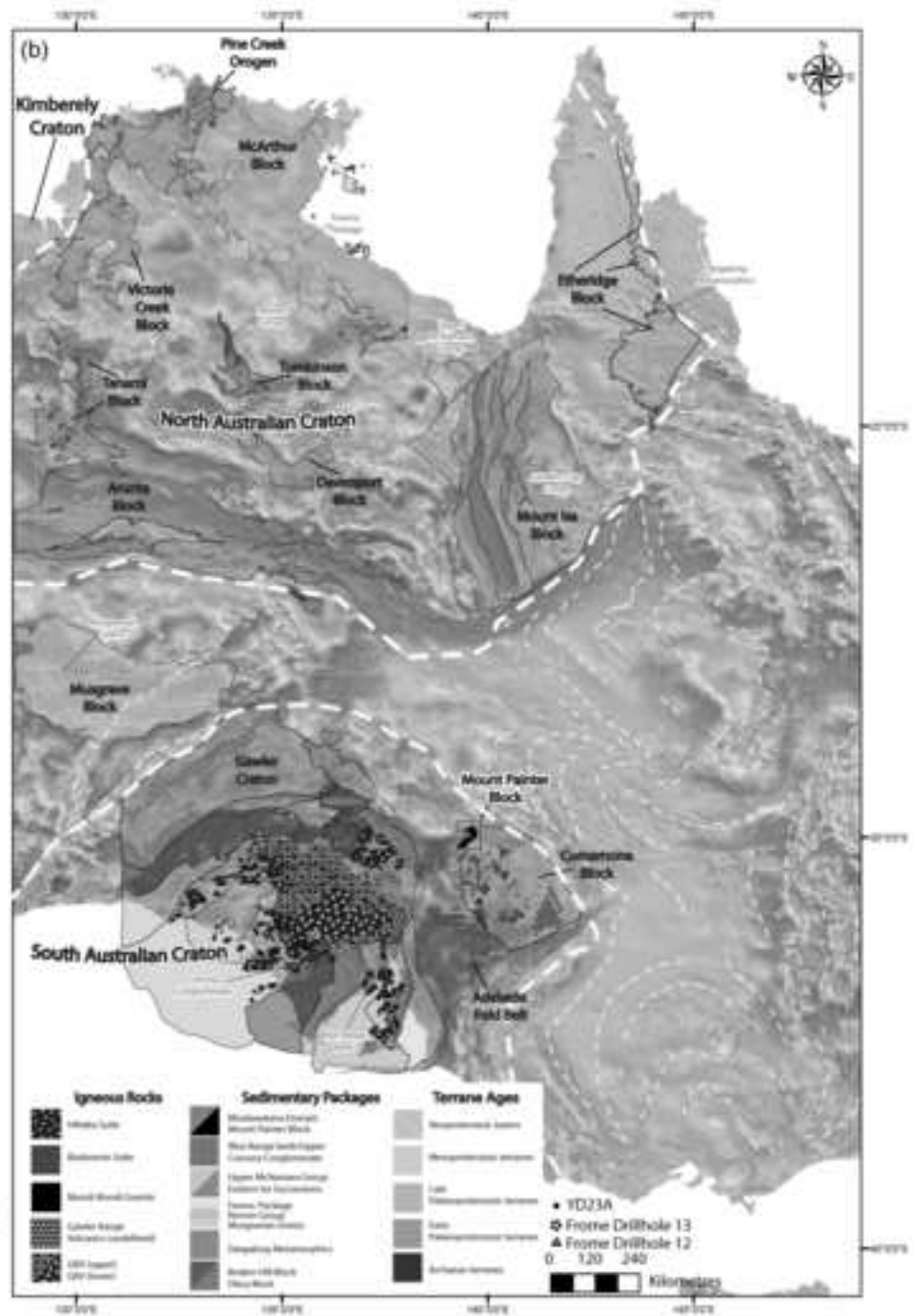
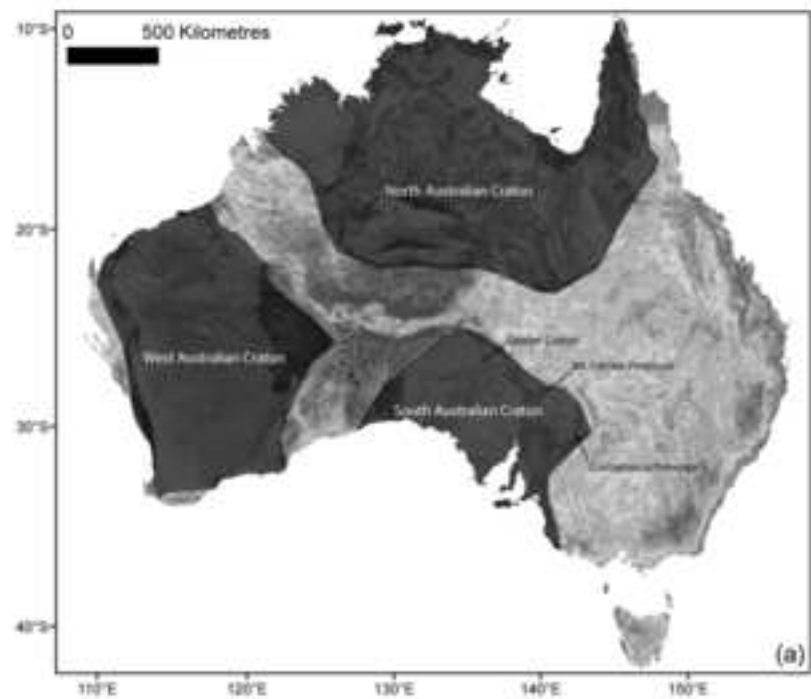


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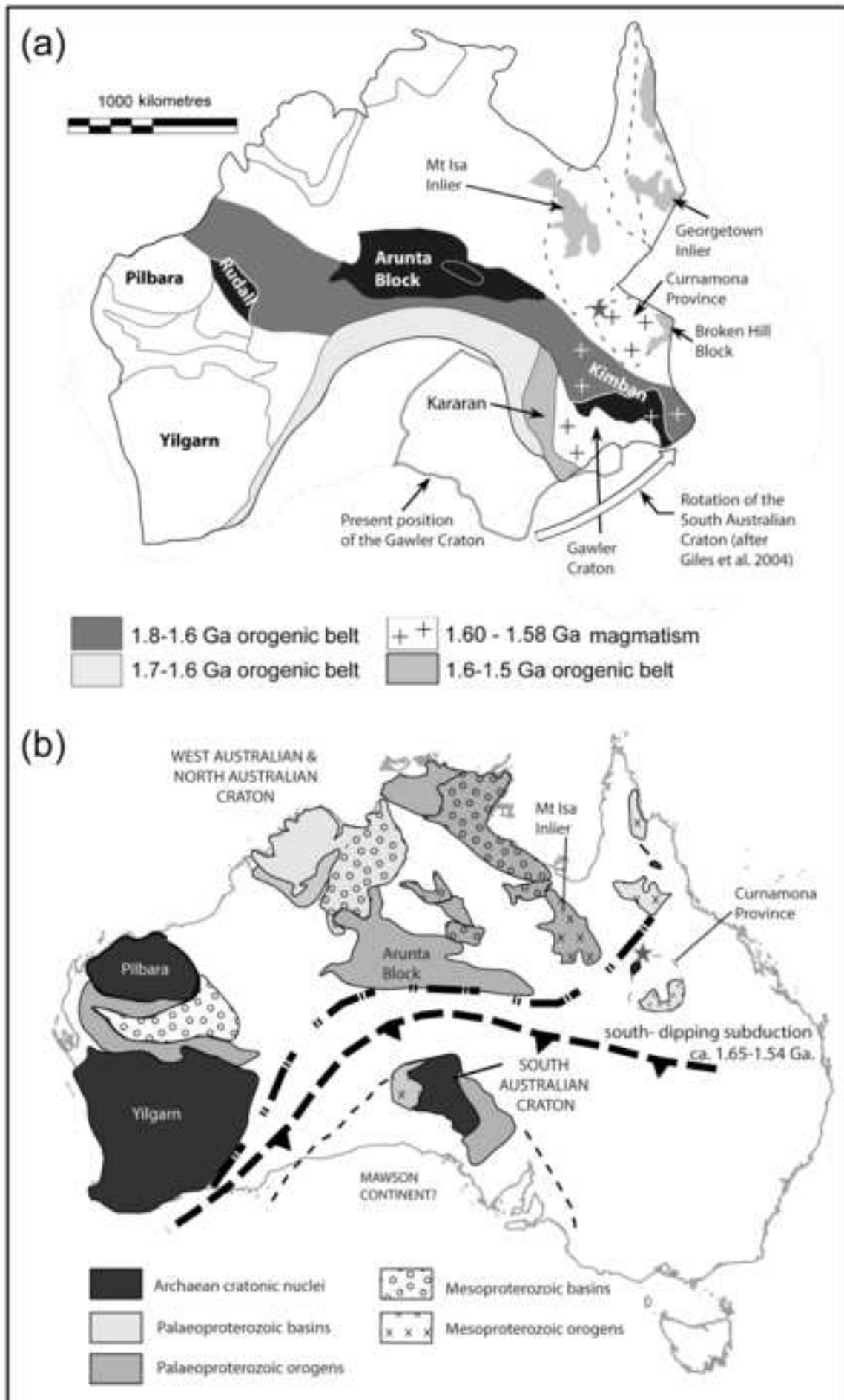


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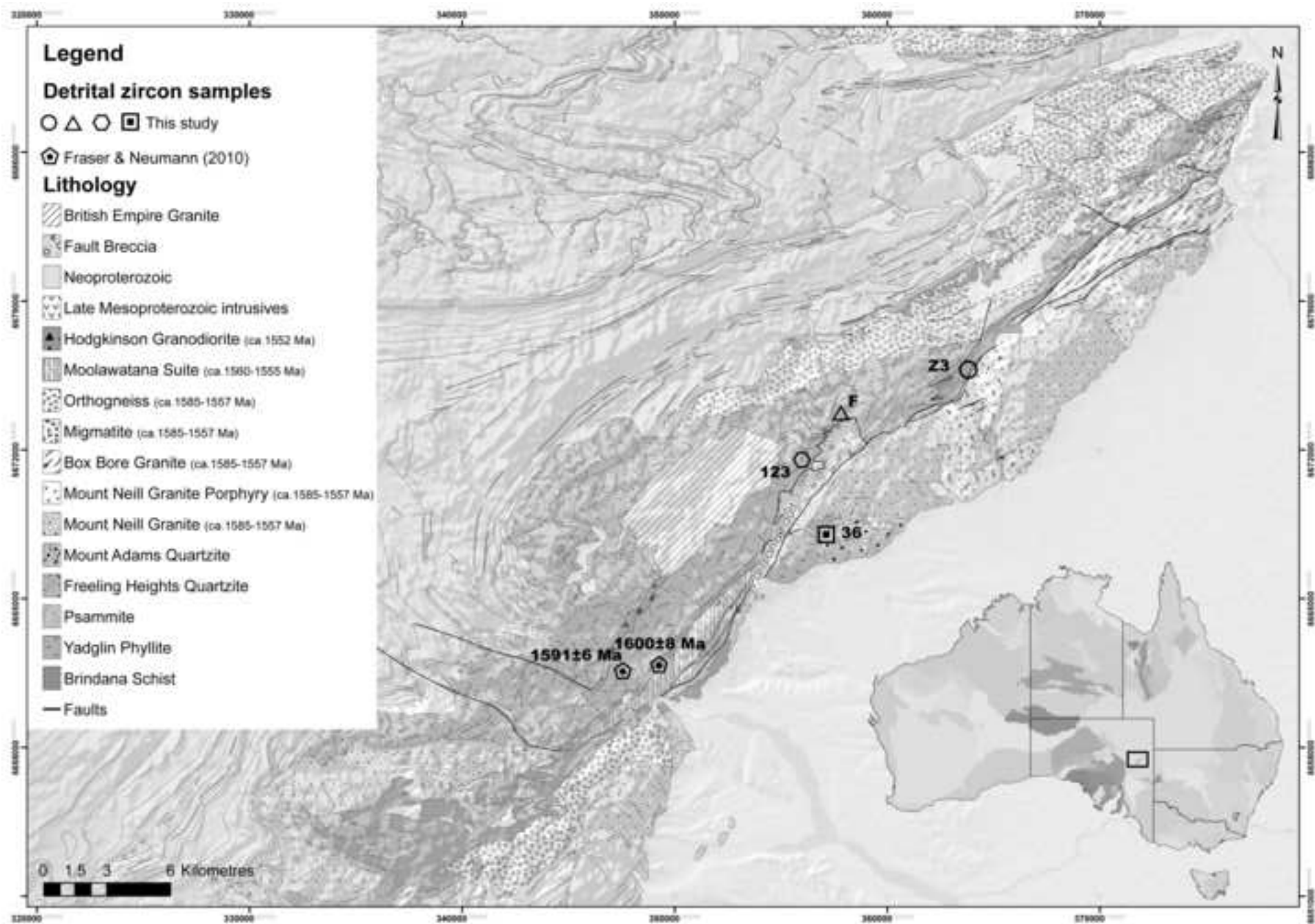


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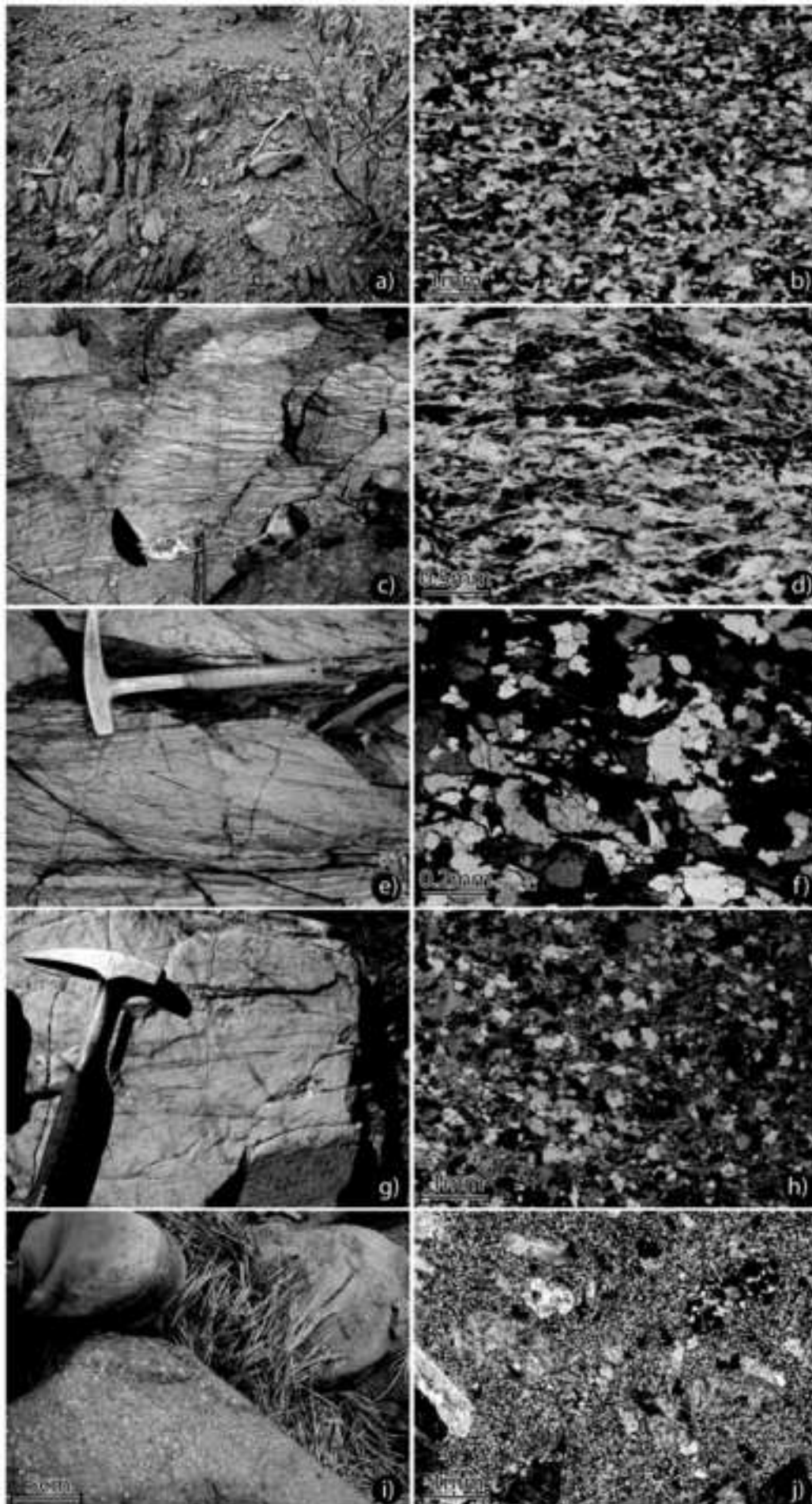


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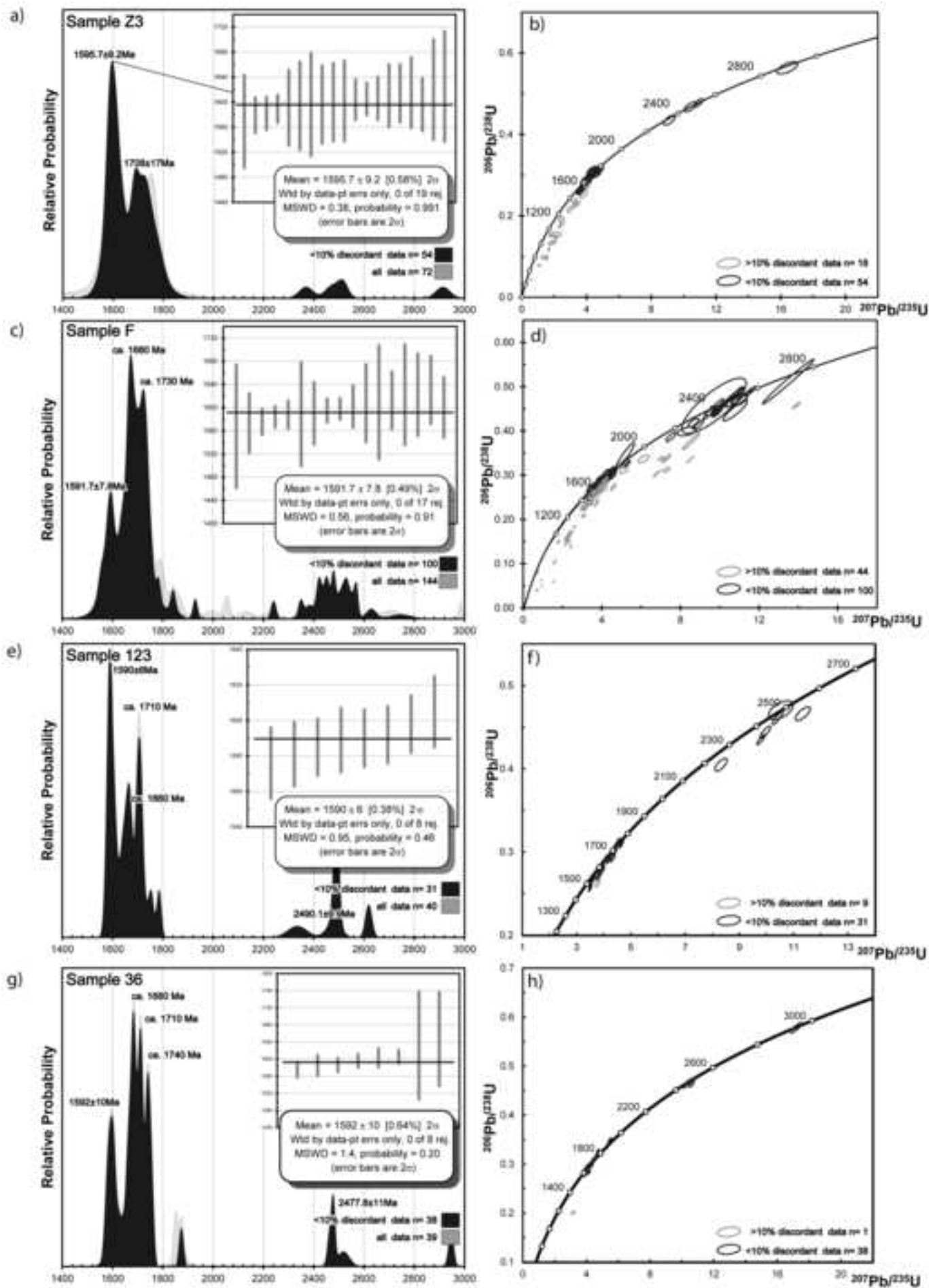


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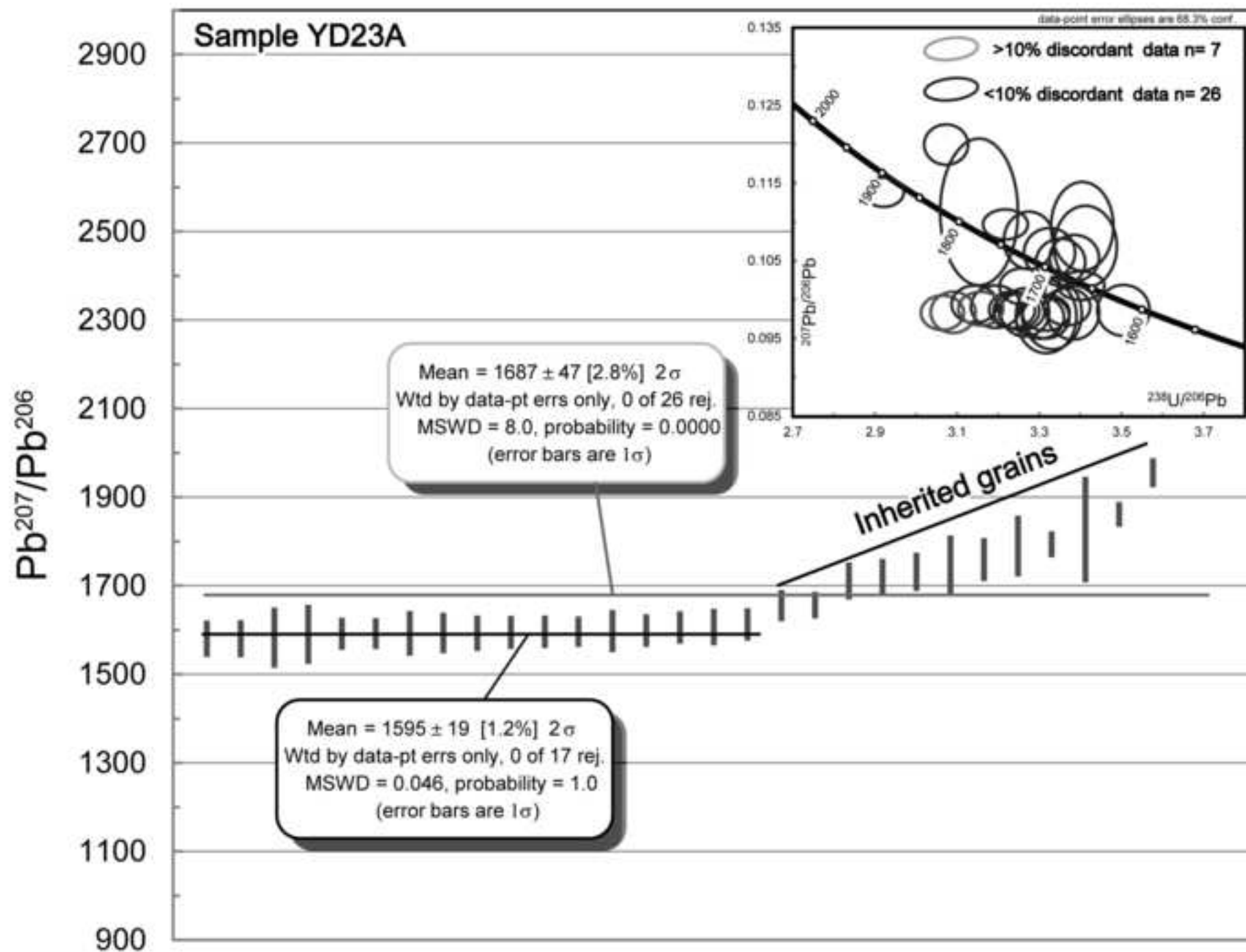


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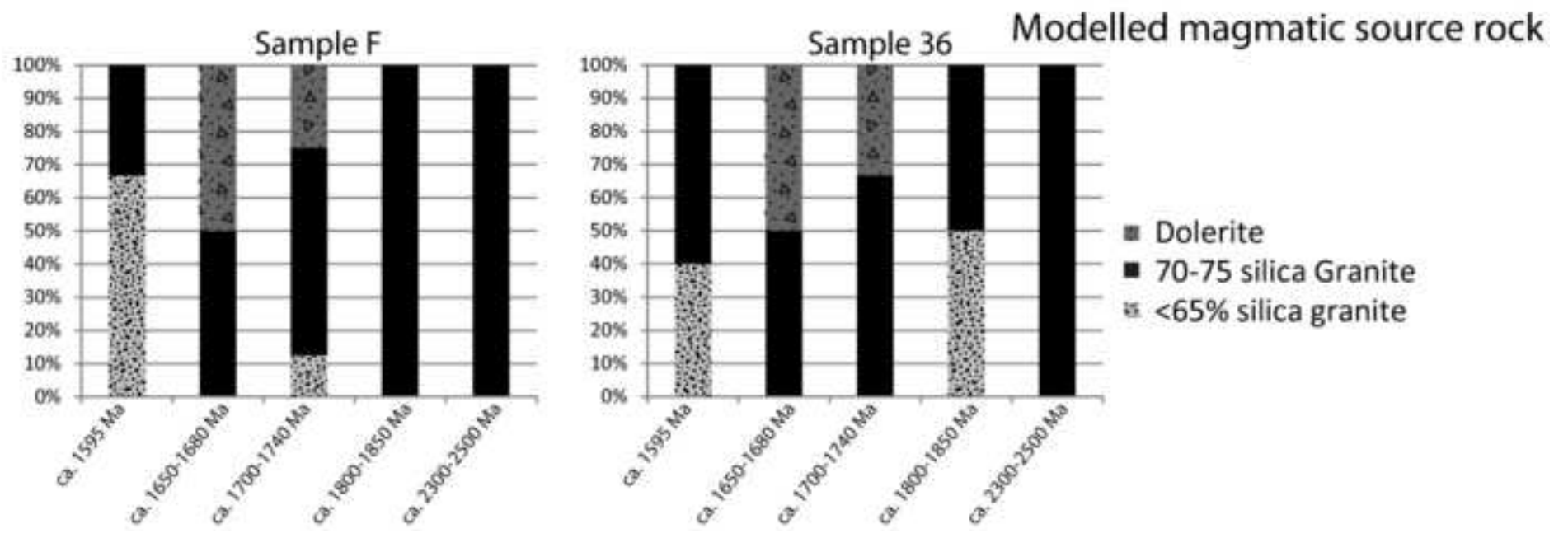
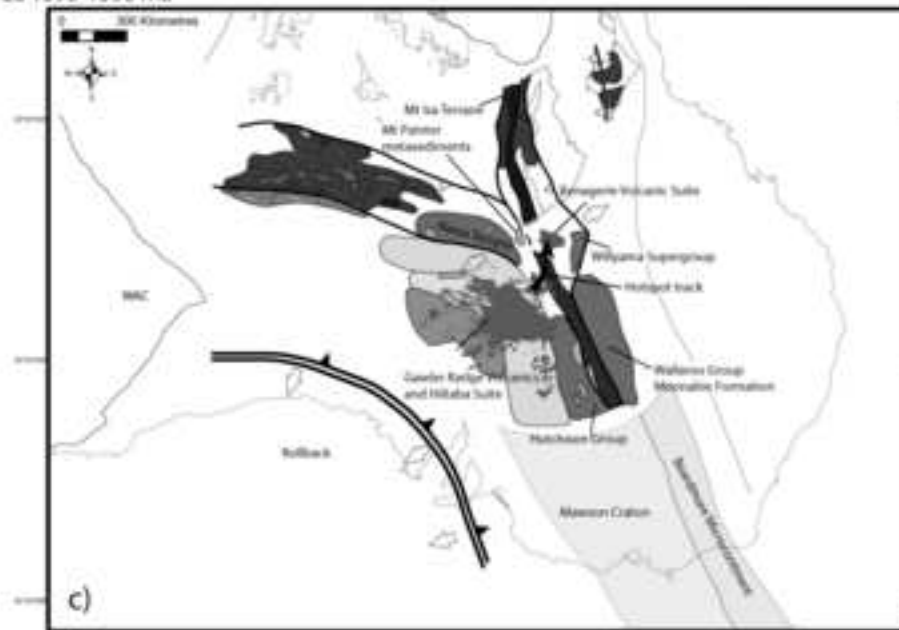


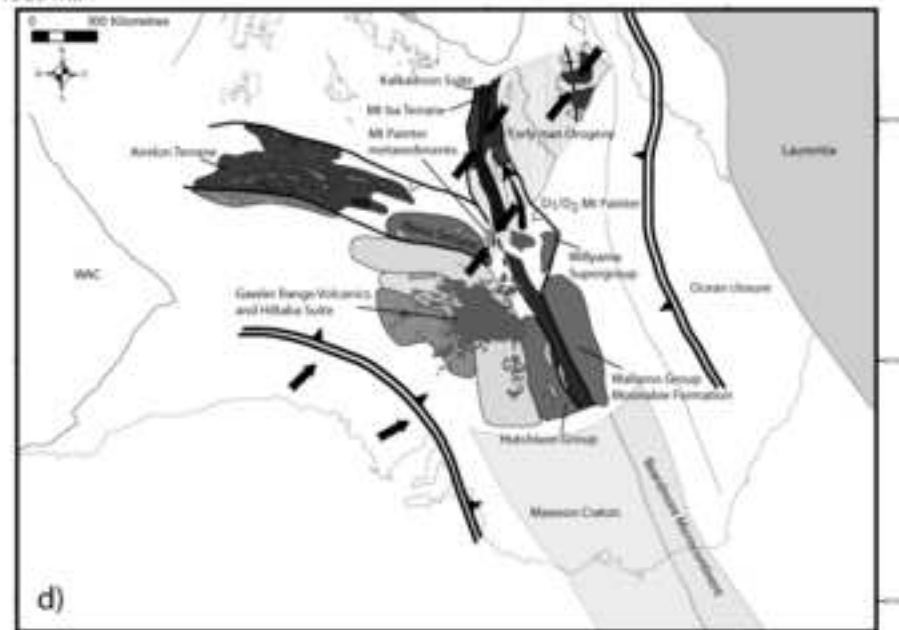


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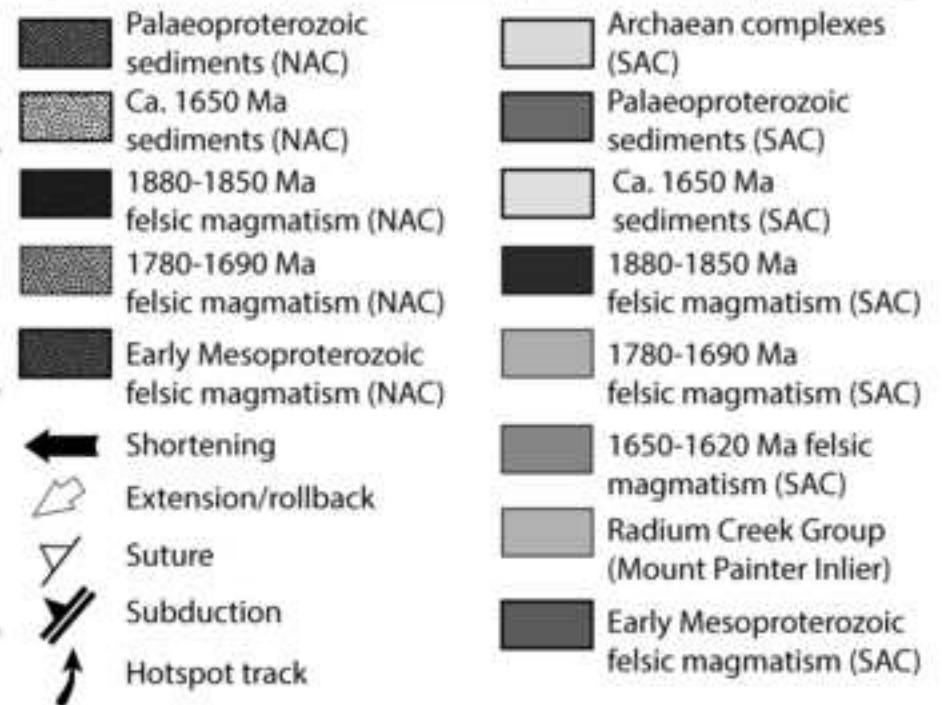
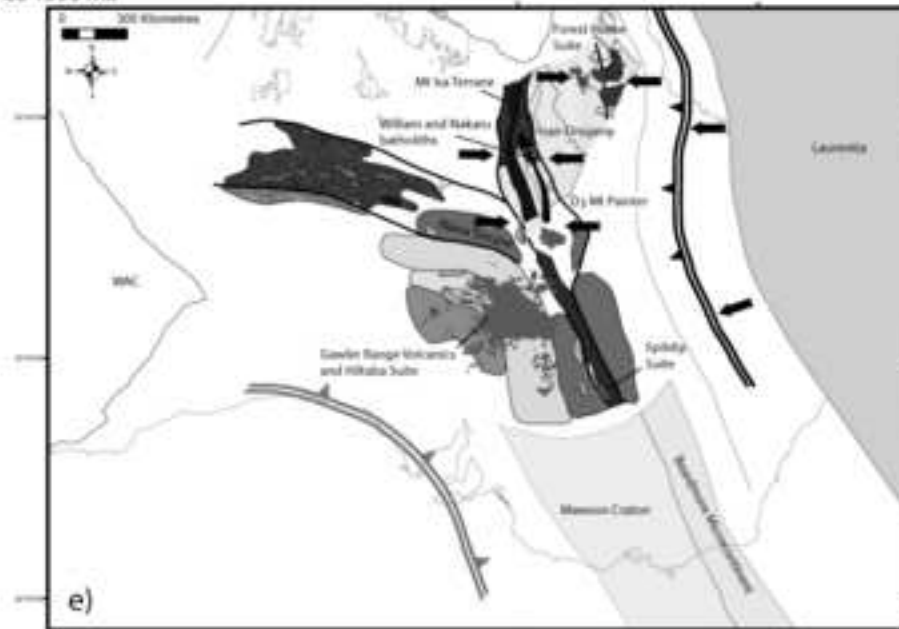
Ca 1595-1590 Ma



Ca 1585 Ma



Ca 1555 Ma



## Figure Captions

Fig. 1: a) Map of Australia showing the geography-based nomenclature after Myer et al. (1996) in which the continent is divided into three major cratonic units, called the North, West and South Australian cratons draped over a composite of the bouguer gravity and first vertical derivative of the total magnetic intensity (TMI) map of Australia (geophysical data provided by Geoscience Australia); b) Map highlighting the location of the Mount Painter Block and other eastern Australian Proterozoic terranes in relation to the major geological provinces of Australia. These are draped across a composite total magnetic intensity (TMI) anomaly and first vertical derivative of the TMI map of Australia. This magnetic image was produced using a two kilometre grid spacing and by applying a low pass filter (upward continued six kilometres), which highlights the longer wavelengths/major structural elements of eastern Australia. Data provided by Geoscience Australia; c). Map showing the position of the Mount Painter Province (grey box) in respect to the major domains and Archaean to Mesoproterozoic geology of the Curnamona Province after Conor and Preiss (2008) and the Gawler Craton modified after Fairclough et al. (2003) and Hand et al. (2007).

Fig 2: a) Palaeogeographical reconfiguration model after Giles et al. (2004); Betts and Giles (2006) supporting a shared history for the South Australian Craton and the North Australian Craton between ca. 1800 and 1550 Ma. This configuration aligns contemporaneous orogenic belts across the Gawler Craton, Arunta Inlier, Mount Isa Inlier and the Curnamona Province.; b) Palaeogeographical reconfiguration model after Wade et al. (2006) in which the Gawler Craton and Curnamona Province are separated by a south-dipping subduction zone between ca.1600-1580 Ma with the Gawler Craton positioned in the overriding plate.

Fig. 3: Map of the Mount Painter Inlier showing sample locations and regional geology after Armit et al. (2012).

Fig. 4: a) Photograph of the steeply dipping, foliated psammopelites of the Brindana Schist unit at the base of Radium Creek Group, geo-pick shown for scale (sample Z3 363800E 6675681N); b) Photo-micrograph of a thin section of sample Z3 from the Brindana Schist in cross-polarised light, cut normal to the  $S_3$  foliation. This view demonstrates overprinting, spaced foliations defined by muscovite  $\pm$  biotite fabrics (sub-horizontal in photo-micrograph) and recrystallised polygonal quartz aggregate (microlithons); c) Photograph of the intensely crenulated, micaceous quartzite outcrop of the Freeling Heights Quartzite (sample F 357632E 6673138N); d) Photo-micrograph of a thin section of the Freeling Heights Quartzite in cross-polarised light. The section, taken normal to the  $S_3$  foliation, highlights a spaced schistosity defined by muscovite with elongate relic quartz grains which display undulose extinction. A discrete crenulation cleavage overprints the existing schistosity; e) Photograph of quartzite unit of the Freeling Heights Quartzite (sample 123 355996E, 6672099N). Cross-beds defined by heavy minerals and distinct compositional layering (compare with bottom right of picture) record reverse grading. This indicates that younging is upwards and towards the west (head of the geo-pick is orientated E-W); f) Photo-micrograph of sample 123 in cross-polarised light. The section was cut normal to the  $S_3$  foliation and highlights two spaced and overprinting foliations defined by biotite  $\pm$  muscovite and polygonal quartz-rich microlithons; g) Photograph of the fine-grained pinky-grey micaceous quartzite outcrop of the Mount Adams Quartzite (Sample 36; 357161E, 6668472N). Cross beds defined by heavy minerals indicate upward younging; h) Photo-

micrograph of sample 36 in cross-polarised light shows fine grained muscovite, sercite and quartz-rich assemblage. A sub-horizontal spaced foliation, defined by fine-grained micaceous material, overprints an earlier mica fabric with polygonal undulose quartz and biotite microlithons; i) Photograph of a hand specimen from the Pondanna member of the upper Gawler Range Volcanics (573593E, 6405524N) showing porphyritic texture with phenocrysts of quartz and feldspar within a dark, aphanitic groundmass; j) Photo-micrograph of Sample YD23a from the Pondanna member of the upper Gawler Range Volcanics (573593E, 6405524N), section shows phenocrysts of k-feldspar, quartz, and pyroxene within a fine grained matrix .

Fig. 5: Cathodoluminescence and back scatter electron images (a-d & e-j respectively of representative zircon grains from each sample analysed in this study. The region ablated during analysis is indicated; a) Z1-29a,b zircon grains from sample Z3 (Brindana Schist). Z1-29a grain has a U-Pb age  $1659 \pm 15$  Ma and an  $\epsilon\text{Hf}$  value of +5.80, Z1-29b grain has a U-Pb age of  $1604 \pm 16$  Ma and a  $\epsilon\text{Hf}$  value of -6.1; b) Z3-24 zircon grain from sample Z3 (Brindana Schist). This grain has a U-Pb age of  $2369 \pm 28$  Ma and an  $\epsilon\text{Hf}$  value of -4.89; c) F6 zircon grain from sample F (Freeling Heights Quartzite). This grain has a U-Pb age of  $1670 \pm 10$  Ma and an  $\epsilon\text{Hf}$  value of +0.01; d) F9 zircon grain from sample F (Freeling Heights Quartzite). This grain has a U-Pb age of  $2539 \pm 28$  Ma and an  $\epsilon\text{Hf}$  value of +1.29; e) 36-13 zircon grain from sample 36 (Mount Adams Quartzite). This grain has a U-Pb age of  $1596 \pm 8$  Ma and an  $\epsilon\text{Hf}$  value of -1.79; f) Back scatter electron image of 36-10 zircon grain from sample 36 (Mount Adams Quartzite). This grain has a U-Pb age of  $1678 \pm 29$  Ma and an  $\epsilon\text{Hf}$  value of -1.64; g) 123-17 zircon grain from sample 123 (Freeling Heights Quartzite). This grain has a U-Pb age of  $1589 \pm 9$  Ma; h) 123-1 zircon grain from sample 123 (Freeling Heights Quartzite). This grain has a U-Pb age of  $1712 \pm 8$  Ma; i) YD23a-7 zircon grain from sample YD23a (uGRV). This grain has a U-Pb age of  $1596.2 \pm 36$  Ma and an  $\epsilon\text{Hf}$  value of -2.74; j) YD23a-27 zircon grain from sample YD23a (uGRV). This grain has a U-Pb age of  $1597.6 \pm 47$  Ma and a  $\epsilon\text{Hf}$  value of -4.5.

Fig. 6: a) Probability plot of detrital zircons analysed from sample Z3. Inset: weighted mean  $^{207}\text{Pb}/^{206}\text{Pb}$  ( $2\sigma$ ) age plot for the youngest population in this sample, interpreted as the maximum depositional age.; b) Concordia plot for zircons analysed from sample Z3 ;c) Probability plot of detrital zircons analysed from sample F. Inset: weighted mean  $^{207}\text{Pb}/^{206}\text{Pb}$  ( $2\sigma$ ) age plot for the maximum depositional age of this sample; c) Zircon grains from sample F plotted on a U-Pb concordia plot; d) Concordia plot for zircons analysed from sample F; e) Detrital zircon probability plot from sample 123. Inset: weighted mean age  $^{207}\text{Pb}/^{206}\text{Pb}$  ages ( $2\sigma$ ) for the maximum depositional age ; f) Concordia diagram for zircons analysed from sample 123; g) Probability plots for zircon analysed from sample 36. Inset: weighted mean  $^{207}\text{Pb}/^{206}\text{Pb}$  ages ( $2\sigma$ ) for the maximum depositional age for this sample; h) U-Pb concordia plot for zircon analysed from sample 36.

Fig. 7: Weighted mean  $^{207}\text{Pb}/^{206}\text{Pb}$  ages plot for sample YD23a showing the dominant population and older inherited grains. Inset: Tera-Wasserburg concordia plot shows the concordant (<10% discordant) analyses, as well as all data >10% discordant from this sample. Data error ellipses and error bars used are  $1\sigma$ .

Fig. 8: a) Plot of  $\epsilon\text{Hf}_{(t)}$  versus  $^{207}\text{Pb}/^{206}\text{Pb}$  ages for the Radium Creek Group samples; b) Plot of  $T_{\text{DM}}^c$  versus  $^{207}\text{Pb}/^{206}\text{Pb}$  ages for the Radium Creek Group samples; c) Plot of  $\epsilon\text{Hf}_{(t)}$  versus  $^{207}\text{Pb}/^{206}\text{Pb}$  ages for the Radium Creek Group samples including values for ARK661 sample from Elburg et al. (2012) compared with the values for the upper Gawler Range Volcanics, uGRV from the Gawler Craton (sample YD23a), and the Frome Granite of the Bimbowrie Suite (sample FG12) and Benagerie Volcanic Suite (sample BV) from the Curnamona Province (see Fig. 1c-d for sample locations). Inset shows a plot of  $T_{\text{DM}}^c$  versus  $^{207}\text{Pb}/^{206}\text{Pb}$  ages for these samples; d) Field for the Radium Creek Group  $\epsilon\text{Hf}_{(t)}$  values plotted as gridded density and data points for comparison. Density grid constructed

using cell size of 20 Myr in the X direction and 0.5  $\epsilon$  Hf units in the Y direction, a threshold level of 0.05 and a smoothing level of 3.

Fig. 9: Comparison of zircon crystallisation rock type, modelled from in-situ trace chemistry after Belousova et al. (2002) to determine the source rock type of zircon grains across the Paralana Fault. Sample F (357632E 6673138N) is from the Freeling Heights Quartzite to the west (Hangingwall) of the Paralana Fault. Sample 36 (357161E, 6668472N) is from the Mount Adams Quartzite to the east (Footwall) of the Paralana Fault. The modelled source rock type is predominantly felsic and indistinguishable across the Paralana Fault.

Fig. 10: Stratigraphic and structural framework of the Mount Painter Inlier using data from this study and Armit et al. (2012). Proterozoic magmatic ages determined using U-Pb geochronology by LA-ICPMS and SHRIMP where available. Mount Neill Granite and porphyry age from Teale (1987, unpublished), Elburg et al. (2003), Neumann (2001), Neumann et al. (2009) and Fraser and Neumann (2010). Northern Gawler tectonism from Payne et al. (2008), Fanning et al. (2007), Thomas et al. (2008), Swain et al. (2005b) and Skirrow et al. (2007). Southern Gawler tectonism from Stewart and Betts (2010), Webb et al. (1986) and Parker et al. (1993). Southern Curnamona Province tectonism from Conor and Preiss (2008), Forbes et al. (2008), Betts et al. (2002), Stüwe and Ehlers (1997), Forbes and Betts (2004), Forbes et al. (2004), Stevens et al. (1988), Wilson and Powell (2001), Page et al. (2000, 2005), Rutherford et al. (2007), Marjoribanks et al. (1980) and Clarke et al. (1987, 1995). Georgetown tectonism from Black et al. (1979), Withnall et al. (1996), Hills (2004), Cihan et al. (2006), Davis (1996), Betts et al. (2009), Boger and Hansen (2004), Black and Withnall (1993), Black et al. (1998), Withnall et al. (1988), Withnall et al. (1996), Blewett et al. (1998) and Bell and Rubenach (1983). Tectonism in the Eastern Fold Belt of the Mount Isa Inlier from Betts et al. (2006), MacCready et al. (1998), Giles et al. (2006a), O'Dea et al. (2006), Page and Sun (1998), Giles and Nutman (2002), Hand and Rubatto (2002), Giles and Nutman (2003), De Jong and Williams (1995), Betts et al. (2006), Connors and Page (1995) and O'Dea et al. (1997). West Fold Belt tectonism from O'Dea and Lister (1995), O'Dea et al. (1997), Lister et al. (1999), Hand and Rubatto (2002), Connors and Page (1995), O'Dea et al. (1997), MacCready et al. (1998), Betts et al. (2006) and Blenkinsop et al. (2008). Tectonism in the Arunta Block after (Claoué-Long et al., 2008; Collins and Shaw, 1995; Collins and Williams, 1995; Maidment et al., 2005; Scrimgeour et al., 2005). Stratigraphy after Armit and Betts (2011) and references therein.

Fig. 11: a) Plot of  $\epsilon$  Hf<sub>(t)</sub> versus  $^{207}\text{Pb}/^{206}\text{Pb}$  ages for Archaean to Mesoproterozoic zircon populations for the major domains of the Gawler Craton from Belousova et al. (2009); Howard et al. (2009;2010;2011a;2011b); Szpunar et al. (2011), compared with the samples from the Radium Creek Group (this study); b) Field for the Gawler Craton  $\epsilon$  Hf<sub>(t)</sub> values from Belousova et al. (2009); Howard et al. (2009;2010;2011a;b); Szpunar et al. (2011) plotted as gridded density and data points for comparison with the samples from the Radium Creek Group plotted as points. Density grid constructed using cell size of 20 Myr in the X direction and 0.5  $\epsilon$  Hf units in the Y direction, a threshold level of 0.05 and a smoothing level of 3.

Fig. 12: a) Plot of  $\epsilon$  Hf<sub>(t)</sub> versus  $^{207}\text{Pb}/^{206}\text{Pb}$  ages for Archaean to Mesoproterozoic zircon populations from the Arunta Block (Hollis et al. 2010) displayed as a gridded density field compared with the samples from the Radium Creek Group shown as points; b) Plot of  $\epsilon$  Hf<sub>(t)</sub> versus  $^{207}\text{Pb}/^{206}\text{Pb}$  ages for Archaean to Mesoproterozoic zircon populations from the Broken Hill Block of the Curnamona Province (Condie et al. 2005) displayed as a gridded density field, compared with the samples from the Radium Creek Group shown as points; c) Plot of  $\epsilon$  Hf<sub>(t)</sub> versus  $^{207}\text{Pb}/^{206}\text{Pb}$  ages for Archaean to Mesoproterozoic zircon populations from the Broken Hill Block of the Mount Isa Inlier (Griffin et al. 2006) displayed as a gridded density field compared with the samples from the Radium Creek Group shown as points. All U-Pb dates shown as  $^{207}\text{Pb}/^{206}\text{Pb}$  ages, Hf isotope values recalculated using a

decay constant of  $1.865E10^{-11}/\text{yr}$ . Density grids for the Radium Creek Group, Gawler Craton, Curnamona Province and Mount Isa Inlier are constructed using cell size of 20 Myrs in the X direction and  $0.5 \epsilon$  Hf units in the Y direction, a threshold level of 0.05 and a smoothing level of 3.

Fig 13: a) Palaeogeographical reconstruction of eastern Proterozoic Australia at ca. 1595 Ma adapted after Giles et al. (2004); Betts and Giles (2006); Betts et al. (2006;2007;2009). In this model the Radium Creek Group are deposited in an extensional back-arc basin and sourced from the Felsic large igneous province (FLIP) preserved on the Gawler Craton; b) Rapid tectonic switching to shortening ca. 1585 Ma and back to extension is driven by perturbations in the convergent margins along the southern margin of Australia; c) Renewed crustal shortening at ca. 1555 Ma is related to subduction along the eastern margin of the continent.

Table 1: Lu-Hf values for standards run to determine instrumentation precision and accuracy.

Table 2: U-Pb values for standards run during the study acquisition period and longer-term averages indicating the level of reproducibility and instrument stability obtained.

Table 3: Summary of the U-Pb dating and Hf isotope analysis.

Table 4: Zircon crystallisation rock type, modelled rock type from in-situ trace element chemistry after Belousova et al. (2002).

**U-Th-Pb and Lu-Hf data**

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**Major and trace geochemistry**

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