Palaeo- to Mesoproterozoic Evolution of the Gawler Craton, Australia: Geochronological, geochemical and isotopic constraints

Justin L. Payne, B.Sc (Hons)

Geology and Geophysics
School of Earth and Environmental Sciences
The University of Adelaide

This thesis is submitted in fulfilment of the requirements for the degree of Doctor of Philosophy in the Faculty of Science, University of Adelaide

January 2008
# Table of Contents

Abstract ........................................................................................................................................... i

Acknowledgments .............................................................................................................................. iii

Publications and Conference abstracts ............................................................................................ iv

Declaration .......................................................................................................................................... v

Chapter One - Introduction ............................................................................................................. 1

Introduction ......................................................................................................................................... 1

Thesis Outline ..................................................................................................................................... 5

Chapter Two - Optimisation of laser ablation conditions for LA-ICP-MS U-Pb monazite
geochronology ................................................................................................................................. 11

2.1 Introduction .................................................................................................................................. 11

2.2 Instrumentation ............................................................................................................................. 13

2.3 Methods ....................................................................................................................................... 14

2.4 Optimisation Experiments Results ............................................................................................. 15

2.5 Discussion of Optimisation Experiment Results .......................................................................... 17

2.5.1 Optimisation of laser ablation for current method ................................................................... 17

2.5.2 Implications of results for LA-ICP-MS U-Pb geochronology ................................................... 18

2.6 Conclusions ................................................................................................................................. 20

Appendix 2.1 Composition of MAdel monazite ............................................................................... 23

Appendix 2.2 Data for laser optimisation tests ................................................................................ 24

Chapter Three - Provenance of metasedimentary rocks in the northern Gawler Craton, Australia:
Implications for Palaeoproterozoic reconstructions ......................................................................... 27

3.1 Introduction .................................................................................................................................. 27

3.2 Geological Background ................................................................................................................ 28

3.3 Samples and Analytical Methods ............................................................................................... 30

3.4 Results ......................................................................................................................................... 30

3.4.1 Major and Trace element geochemistry and Sm-Nd isotope systematics ............................... 32

3.4.2 U-Pb detrital zircon geochronology ....................................................................................... 32

3.5 Discussion .................................................................................................................................... 34

3.5.1 Timing of deposition and source characteristics ..................................................................... 34

3.5.2 Provenance of the Nawa Domain metasedimentary rocks .................................................... 37

3.5.3 Correlations and implications for reconstruction of Proterozoic Australia ............................ 39

3.6 Conclusions .................................................................................................................................. 40

Appendix 3.1 U-Pb detrital zircon geochronology data ................................................................. 47

Appendix 3.2 Detrital zircon U-Pb geochronology for samples 650703 from Manya 4 DDH .............. 52

Chapter Four - Temporal constraints on the timing of high-grade metamorphism in the northern
Gawler Craton: implications for assembly of the Australian Proterozoic ........................................ 57

4.1 Introduction .................................................................................................................................. 57

4.2 Geological Setting ......................................................................................................................... 58

4.3 Sampling and Methods ............................................................................................................... 61

4.4 Sample Description ...................................................................................................................... 62

4.4.1 Mt Furner 1 - Central-northern Nawa Domain ..................................................................... 62

4.4.2 Manya 4 - Central-northern Nawa Domain .......................................................................... 62

TOC.1
Chapter Five - Assessment of a subduction-related petrogenesis for the Palaeoproterozoic Tunkilla Suite, Gawler Craton, Australia: implications for reconstruction models of Proterozoic Australia

Chapter Six - Early Mesoproterozoic crustal anatexis in the Gawler Craton, South Australia
6.6.2.3 Coeval or cogenetic origin of the Pt James intrusion? ........................................... 135
6.6.2.4 Petrogenesis of the Munjeela Suite .............................................................. 135
6.6.3 Age and Significance of metasedimentary enclaves ............................................... 136
6.6.4 Early Mesoproterozoic metamorphism and crustal thickening on the Gawler Craton. 137

6.7 Conclusions ........................................................................................................... 138

Chapter Seven - A global context for the Palaeoproterozoic evolution of the Mawson Continent... 145

7.1 Introduction ............................................................................................................. 145
7.2 The Mawson Continent .......................................................................................... 148
  7.2.1 The Gawler Craton .............................................................................................. 152
    7.2.2.1 Late Archaean-Early Palaeoproterozoic ......................................................... 152
        7.2.1.2 c. 2.0 Ga Militalie Event .............................................................................. 152
        7.2.1.3 2.0-1.86 Ga sediment deposition and the c. 1.85 Ga Cornian Orogeny .... 153
        7.2.1.4 1.8 - 1.74 Ga magmatism and sedimentation ........................................... 153
        7.2.1.5 1.73 - 1.69 Ga Kimban Orogeny ................................................................. 153
        7.2.1.6 1.66 Ga Ooldean Event ............................................................................... 154
        7.2.1.7 Palaeo-Mesoproterozoic Transition Events .............................................. 154
    7.2.2 Archaean-Palaeoproterozoic Antarctica ............................................................ 154
        7.2.2.1 Terre Adelie Craton .................................................................................... 155
        7.2.2.2 Miller Range ............................................................................................... 156
        7.2.2.3 Shackleton Range ...................................................................................... 156
  7.3 Assembling the Mawson Continent ....................................................................... 156
    7.3.1 The Gawler-Adelie-Miller Range-Shackleton Range 1.7 Ga connection .......... 157
    7.3.2 The western extent of the Mawson Continent .................................................. 157
  7.4 Tectonic Reconstruction Models for the Mawson Continent ................................. 158
  7.5 Towards a Unified Model for the evolution of the Mawson Continent ................... 163
    7.5.1 Palaeogeometry of the Gawler Craton and related terranes ............................ 163
    7.5.2 Evolution of the Gawler-Adelie Craton and Mawson Continent in a global setting ... 166
        7.5.2.1 Late Archaean-Early Palaeoproterozoic ..................................................... 166
        7.5.2.2 2.0 Ga to 1.85 Ga rifting and sedimentation .............................................. 167
        7.5.2.3 1.85 Ga Orogenesis and crustal melting ................................................... 167
        7.5.2.4 1.85 - 1.73 Ga basin formation and magmatism ....................................... 170
        7.5.2.5 1.73 - 1.69 Ga orogeny and sediment deposition ..................................... 171
        7.5.2.6 1.69 - 1.62 Ga accretion, UHT metamorphism and sedimentation .......... 174
        7.5.2.7 Arc-magmatism and orogenesis - 1.62 - 1.5 Ga ...................................... 176
  7.6 Conclusions ........................................................................................................... 177

Supplementary Appendix One - U-Pb geochronology of ‘age-constrained’ monazite from the Harts Range, central Australia ................................................................. A1

Supplementary Appendix Two - Co-authored peer-reviewed publications ...................... A9
List of Figures

1.1 Interpreted basement geology of the Gawler Craton ........................................ 2
1.2 Time-Space diagram for Gawler Craton ......................................................... 3
1.3 Summary of revisions to tectonothermal events in the Gawler Craton ...................... 4
2.1 Monazite LA-ICP-MS geochronology of previous studies ...................................... 10
2.2 U/Pb and Pb/Pb integrated ratios from fractionation experiments .......................... 13
2.3 $^{238}$U/$^{235}$U measured isotope ratios .......................................................... 14
2.4 Comparison of integrated and $\lambda_{0}$ ratios for U/Pb data .................................. 14
2.5 $\lambda_{0}$ isotope ratios for monazite and NIST 610 matrices ................................... 15
2.6 Counts per second for Fractest 2 analyses ...................................................... 16
2.7 Ablation pit cross-sections ........................................................................ 17
2.8 15 $\mu$m and 30 $\mu$m beam comparison data .................................................. 17
3.1 Simplified basement geology of the Gawler Craton ............................................. 27
3.2 CL- images of detrital zircon population ......................................................... 30
3.3 REE spider plots for metasedimentary rock samples ........................................... 32
3.4 $e_{\text{iso}}$ evolution diagram for Nawa Domain samples, average Gawler Craton and Willyama Supersequence ................................................................. 32
3.5 Detrital zircon age spectra .................................................................................. 33
3.6 A-C*NK-FM ternary diagram and Th/Sc v Zr/Sc plot .......................................... 34
3.7 Combined detrital zircon age spectra and comparison with Arunta Region data ...... 36
3.8 Comparative REE spidergram for metasedimentary sequences ............................. 36
3.9 Lower Willyama Sequence detrital zircon age spectra ....................................... 37
3.10 Reconstruction models for the Proterozoic of Australia ...................................... 39
3.10.2.1 Zircon CL images .................................................................................. 50
3.10.2.2 Concordia diagrams and $^{206}$Pb/$^{207}$Pb age spectrum ............................... 51
4.1 Pre-1070 Ma tectonic elements of Proterozoic and Archaean Australia .................... 58
4.2 Simplified interpreted solid geology of the Gawler Craton .................................... 59
4.3 TMI image of Gawler Craton overlain with Kimban Orogeny age-constraints .......... 60
4.4 Microphotographs of metasedimentary lithologies ............................................. 63
4.5 BSE images of representative monazite grains .................................................. 66
4.6 Concordia and weighted mean age plots ........................................................... 67
4.7 TMI data of the Gawler Craton overlain with age constraints of tectonism ............. 75
5.1 Interpreted Basement geology of the Gawler Craton .......................................... 85
5.2 Detail of interpreted basement geology with locations and age constraints for Tunkillia Suite ................................................................. 86
5.3 Plutonic rock classification diagram .................................................................. 90
5.4 Major element classification diagrams of Frost et al. (2001) ................................. 91
5.5 REE chondrite-normalised spider plots fo Tunkillia Suite samples ....................... 92
5.6 Primitive-mantle normalised trace element plots for Tunkillia Suite samples ...... 93
5.7 Nd-isotope growth curves for Tunkillia Suite and selected Gawler Craton lithologies ................................................................. 93
5.8 Distribution of $e_{\text{iso}}$ values for Tunkillia Suite ................................................. 94
5.9 CL-images and concordia diagram for Lake Ifould low- to midum-K lithologies ...... 95
5.10 Tectonic discrimination diagrams for Tunkillia Suite data ................................... 95
5.11 Trace element characterisation plots for Tunkillia Suite data .............................. 97
5.12 P-T diagram with experimentally constrained melt-reaction conditions ............... 98
6.1 Simplified geology of the Gawler Craton ........................................................... 107
6.2 TMI image of south-western Gawler Craton with interpreted geology .................. 108
6.3 Field photographs of Munjeela Suite ................................................................. 110
6.4 Microphotographs of Munjeela Suite granite and metasedimentary enclaves ........ 111
6.5 CL-images and U-Pb age plots for Munjeela Suite granite ................................... 116
6.6 CL-images and U-Pb age plots for metasedimentary enclaves ............................. 121
6.7 Whole-rock geochemistry plots ......................................................................... 126
6.8 Nd-isotope growth curves for Munjeela Suite ........................................127
6.9 Major and Rare-earth element data for magmatic garnet ..........................128
6.10 Garnet Mn-Fe-Mg-Ca compositional maps and traverses .......................129
6.11 P-T pseudosection for sample 06-MJMS-06 ........................................133
6.12 TMI image displaying interpreted structures around Munjeela intrusion localites ........138

7.1 Map of East Gondwana with interpreted extents of Mawson Continent ........146
7.2 Satellite Magnetic Intensity map of Mawson Continent ..........................147
7.3 Palaeomagnetic data for Palaeo- to Mesoproterozoic of Australia ................148
7.4 Simplified geology of Gawler and Adelie Cratons .................................149
7.5 Time-Space plot of selected Australian and East Antarctica terrains ............150
7.6 Simplified geology of the Miller and Shackleton Ranges ..........................155
7.7 Previous tectonic reconstruction models for the Mawson Continent .............160
7.8 Palaeogeometry of the Gawler Craton .............................................165
7.9 Proposed reconstruction model for the Mawson Continent .........................168
7.10 Geology of the North Australian Craton ...........................................171
7.11 Time-Space plot for selected Archaean-Early Palaeoproterozoic terrains .......173
7.12 Detailed Time-Space of metamorphic conditions for orogenic events in northern and central Australia ..........................................................175
Abstract

The Gawler Craton, South Australia, consists of late Archaean to early Mesoproterozoic igneous and supracrustal lithologies which preserve a deformation history lasting the duration of the Palaeoproterozoic. Understanding the evolution of the Gawler Craton is of significance in global supercontinent reconstructions as it preserves evidence for earliest Palaeoproterozoic collisional orogenesis (c. 2460-2430 Ma) and, in conjunction with the North Australian Craton and Antarctica, has often been correlated to the western margin of Laurentia. In addition, the Gawler Craton is also host to the world-class Olympic Dam Fe-oxide-Cu-Au deposit (world’s fourth-largest Cu and largest U deposit) and related Fe-oxide-Cu-Au-U and Cu-Au mineralisation systems. Despite the various geologically and economically important characteristics of the Gawler Craton there has traditionally been a poor understanding of the tectono-thermal evolution of the Gawler Craton, in particular for the Palaeoproterozoic. This study addresses and refines the Palaeo- to Mesoproterozoic tectono-thermal evolution of the Gawler Craton. This is done using geochemical, geochronological and isotopic analytical techniques to better understand selected supracrustal and igneous lithologies in the Gawler Craton and the orogenetic events which have affected them.

Largely unexposed metasedimentary lithologies of the northern Gawler Craton record multiple deformation events but have previously been virtually unconstrained with respect to their timing of protolith deposition and the age of deformation/metamorphism. New geochronological data demonstrate these metasedimentary lithologies were deposited during the time period 1750-1730 Ma before being metamorphosed and deformed during the Kimban (1730-1690 Ma) and Kararan (1570-1545 Ma) Orogenies. Detrital zircon geochronology and isotopic and geochemical characteristics of the sampled metasedimentary lithologies suggest a relatively similar protolith sedimentary succession was deposited across a large extent of the northern Gawler Craton. Detritus for the sedimentary protolith does not appear to have been sourced from the Gawler Craton. Instead the protolith it is more consistent with a North Australian Craton provenance suggesting a proximity between the northern Gawler Craton and North Australian Craton at the time of protolith deposition.

The newly defined presence of the Palaeoproterozoic Kimban Orogeny in the northern Gawler Craton demonstrates the Kimban Orogeny to be a major, high-grade, craton-wide orogenic event. This finding contradicts previous suggestions that the northern Gawler Craton was accreted to the proto-Gawler Craton during the later Mesoproterozoic Kararan Orogeny. In addition, previous reconstruction models for the Palaeo- to early Mesoproterozoic often cite the felsic Tunkillia Suite (1690-1670 Ma), western and central Gawler Craton, as representing arc magmatism prior to the subsequent amalgamation of the Gawler Craton during the Kararan Orogeny. New geochemical and isotopic data for the Tunkillia Suite have allowed for re-examination of the tectonic setting for the petrogenesis of the Tunkillia Suite. Contrary to previous suggestions (based upon discrimination diagrams), the mineralogy, geochemistry and isotopic characteristics of the Tunkillia Suite are not consistent with arc-magmatism. Instead the Tunkillia Suite is interpreted to represent a late- to post-tectonic magmatic suite generated during the waning stages of the Kimban Orogeny. This petrogenesis further highlights the importance of the Kimba Orogeny as a fundamental tectono-thermal event in the evolution of the Gawler Craton.

Subsequent to the Kimban Orogeny, the Gawler Craton was thought to undergo a period of subduction-related magmatism (St Peter Suite) prior to the anorogenic magmatism of the voluminous felsic Gawler Range Volcanic (GRV) and Hiltaba Suite magmatism (1595-1575 Ma). New geochronological data for the ms-bi-gt-bearing peraluminous Munjeela Suite (1590-1580 Ma) have demonstrated the Hiltaba/GRV event was accompanied by significant crustal anatexis not associated with the Hiltaba/GRV magmatism. The Munjeela Suite and metasedimentary enclaves within it demonstrate that the Gawler Craton was likely to be undergoing compressive deformation and crustal thickening sometime during the petrogenesis of the Hiltaba/GRV magmatism. This suggests the Hiltaba/GRV magmatism did not occur in an anorogenic setting as previously proposed.

The findings of this study are incorporated into a revised tectono-thermal evolution of the Gawler Craton. This is used to discuss previous reconstruction models for Proterozoic Australia and provide a new reconstruction model of Australia and Antarctica during the Palaeoproterozoic. Important facets of the proposed model are links to the Archaean-Early Palaeoproterozoic Sask Craton in the Trans-Hudson Orogen, Laurentia, and the joint evolution of the North Australian and Gawler Cratons throughout the entire Palaeoproterozoic.
Acknowledgements

First and foremost I would like to thank my supervisors, Karin and Martin. Both have been the providers of excellent supervision. I may still have ended up at this point without the Gawler LP but I doubt the process would have been anywhere near as enjoyable and enlightening. I think the level of enjoyment myself and the other PhDers have had is a reflection of the fantastic culture they have created within the research group.

I think an honourable mention is befitting for Anthony Reid and Angus Netting of the PIRSA and Adelaide Microscopy worlds, respectively. Anthony has acted in many ways as a third supervisor, especially with the final epic, but mainly has provided enjoyable discussions and wisdom on many things Gawler-related and a few other things too. Angus has had the pleasure of setting up a LA-ICP-MS (and letting Ben and I watch and play too), numerous weekend phone calls and more than a couple late carbon-coats. His good humour has made the many long hours in the med. school basement more bearable.

Pete Kinny is thanked for guidance and expertise with the SHRIMP geochronology conducted at Curtin University of Technology.

My self-appointed mentor Ben Wade who has provided many hours of entertainment, lurid laser, zircon and monazite talk and even some useful advice on the world of geochemistry and geochronology. I probably didn't pay enough attention to be a worthy protégé but somehow Karin's lab geeks worked out how to do stuff. The fellow CERGers of the recent past and present for providing all forms of conversations on most of the topics worth covering and many not over the last three and a half years (actually three quarters). Rian Dutch (a co-starter), Chris Clark (an unofficial Honours supervisor), Lachie Rutherford and Mike Szpunar (the grumpy old men), Greg Swain (Gawler tour leader and proud ute-owner), Dave E. Kelsey (a late musical addition at a higher, non-student level) and Alisa Schwarz (food orderer extraordinaire).

My family has managed to put up with and support me for over twenty-five years now which I think is a very fine effort. A thesis dedication should go to Mum and Dad for all of their support and work in producing a family I'm more than proud to be a part of. My younger sister, Natalie, who like all young siblings has picked up most of my bad traits and added a few more, which have made sharing a house for the last couple of years a pleasure, most of the time. And although more absent in the last few years, my older sister, Emily, has been able to put up with the rubbish talked between Natalie and I, and more recently her husband, Richard (the only other real doctor in the family).

Outside of PhD life, Shane, Hannah, Aaron and Tim have been the best of friends and hopefully I don't have to say "I'm at uni" quite so much when I answer the phone in the future. And for the excitement of bi-monthly chess, Jessie.

Most importantly I would like to thank Dr. Kate. I often tell her she has never known me outside of a PhD, so of course I'll be a much better person when I'm done. Hopefully this proves to be the case. Regardless, I would like to thank her for all the reading, the long, seemingly unending and sometimes unwanted barrage of geology conversations, all the more normal conversations and for letting me do a PhD the way I have, even though you knew it didn't have to be done that way.

"you might have to think of how you got started sitting in your little room"
Publications and Selected Conference Abstracts

Peer Reviewed Journal Articles


Selected Conference Abstracts


Declaration

This thesis contains no material which has been accepted for the award of any other degree or diploma in any university or other tertiary institution and, to the best of my knowledge and belief, contains no material previously published or written by any other person, except where due reference has been made in the text.

I give consent to this copy of my thesis, when deposited in the University Library, being available for loan and photocopying.

______________________________
Justin L. Payne