Low-temperature thermochronologic insights into the exhumation of the northern Gawler Craton (South Australia)

Max Charles Reddy

November 2014

THE UNIVERSITY of ADELAIDE

LOW-TEMPERATURE THERMOCHRONOLOGIC INSIGHT INTO THE EXHUMATION OF THE NORTHERN GAWLER CRATON (SOUTH AUSTRALIA)

EXHUMATION OF THE NORTHERN GAWLER CRATON

ABSTRACT

The Gawler Craton (South Australia) records a complex thermal history during the Phanerozoic. Previous work has indicated that the central Gawler Craton was largely exhumed during the Carboniferous as a far-field effect of the Alice Springs Orogeny. Besides this widespread exhumation event, localised Mesozoic and Tertiary thermal events have been documented for the central Gawler Craton as well. The extent of these events into the northern Gawler Craton is not well understood as low-temperature thermochronological data is lacking for this region. For this study, granitoid samples along a roughly north-south transect through the northern and central Gawler Craton were analysed using the apatite fission track (AFT) and apatite (AHe) and zircon (ZHe) U-Th-Sm/He methods. Results from these low-temperature methods yield Neoproterozoic through to Cretaceous AFT, AHe and ZHe ages. Cumulative AFT age plots reveal a multi-phase Phanerozoic cooling history for the central and northern Gawler Craton. Significant AFT age peaks were found at ~480-450 Ma and ~350-300 Ma. The Ordovician age peak is thought to be related with the final stages of the Delamerian Orogeny, while the Carboniferous age peak is interpreted as being a far field response to the Alice Springs Orogeny. This is consistent with previous interpretations throughout South Australia. Additionally, localised Jurassic and Cretaceous AFT and ZHe ages were obtained which are thought to be related with rifting at the southern Australian margin and river incision respectively.

KEYWORDS

South Australia, northern Gawler Craton, Low-temperature Thermochronology, Apatite Fission Track, exhumation.

TABLE OF CONTENTS

Low-temperature thermochronologic insight into the exhumation of the Northern Gawler craton (South Australia) 1
Exhumation of the Northern Gawler craton 1
Abstract 1
Keywords 1
List of Figures and Tables 3
Introduction 6
Geological Setting/Background 7
Pre-Phanerozoic tectonic history of the Gawler Craton 7
Phanerozoic tectonic history of the Gawler Craton 9
Samples and Methodology 16
Apatite fission-track thermochronology 16
Apatite and Zircon (U-Th-Sm)/He thermochronology 19
Observations and Results 19
Apatite Fission Track calibration 19
Apatite Fission Track results 23
Apatite and Zircon (U-Th-Sm)/He results 29
HeFTy time-temperature models 33
Discussion 36
Cumulative AFT data 36
Cumulative time-temperature history 43
Conclusions 45
Acknowledgments 46
References 47
Appendix A: Extended Methods 50
Apatite Fission Track Thermochronology 50
Apatite U-Th-Sm/He (AHe) and Zircon U-Th-Sm/He (ZHe) Thermochronology 57
Appendix B: Data reduction input 58

LIST OF FIGURES AND TABLES

Figure 1: Simplified geological map of the Gawler Craton, modified from Howard et al. (2011). Sample locations for this study are indicated by their sample numbers on the map. As shown, a roughly north-south profile was sampled mainly targeting granitoids in the northern and central Gawler Craton. One additional sample (952) comes from a drill core in the Eucla basin..... 8
Figure 2: Regional Map of Australia showing the location of significant Basins and Cratons, adapted from (Boone 2013)..... 14
Figure 3: Radial plot for Durango apatite age calculations used as the international standard in this study. The plot was made using RadialPlotter (Vermeesch 2009). Each point represents the age obtained for individual grains. The age for each grain on the plot is obtained by projecting a line from the origin, through an individual point and to the curved age axis in Ma. The scale on the left shows the standard deviation of the dataset. The further a point plots to the right, the more precise the measurement is, demonstrated by the horizontal precision axis below the plot. For this plot, a central age of 32±1.5 Ma (red line) with a dispersion of 16% was obtained, n represents the number of grains analysed. The maximum and minimum grain ages are highlighted by the two orange lines..... 20
Figure 4: Radial plots showing data obtained for in-house standards from Arkaroola, South Australia. Plots 1 and 2 display data obtained by Dr. Stijn Glorie and Mr. Jack Gillespie respectively. The ARK 717 (UTM coordinates 54J 341962 / 6657785) (image 2 & 3) plot is based on multi-grain data obtained via LA-ICP-MS. The comparable results between image 2 and 3 demonstrate internal consistency. TTN1 (image 1) is located in close proximity to ARK 717 and is based on single-grain data obtained via the classical AFT method (which explains the tighter clustering of the individual data points for TTN1). Comparable results between samples TTN1 and ARK 717 demonstrate the validity of the LA-ICP-MS method. For TTN1 sample details refer to (Weisheit et al. 2014). ARK 717 is an in-house standard with an identical exhumation history to TTN1. Radial plots produced using RadialPlotter software (Vermeesch 2009). See Figure 3 for a description on radial plots..... 22
Figure 5: Simplified geological map overlying a Google Earth satellite image. Modified from Howard et al. (2011). Major intrusions and sample locations are shown. Sample 952 is outlined in blue because it is from drill core as opposed to rock outcrop. ZHe age peaks are in purple font, AFT age peaks in dark green and AHe age peaks in blue. AFT minimum ages are in aqua font. All ages are in Ma. 24
Figure 6: (next page). Radial plots of all samples in this study displaying all low-T data obtained in this study, as well as length histograms where available. Radial plots were constructed using the software program RadialPlotter (Vermeesch 2009). See Figure 3 for a description on radial plots. AFT age peaks are presented as green lines on the plot, ZHe age peaks in purple, AHe age peaks in blue and AFT minimum age peaks in teal. AFT age peaks and statistically acceptable minimum AFT ages were calculated using the automatic mixture model in RadialPlotter. Peak ages are listed alongside peak lines within the plot. For each AFT age peak, the percentage of data used to constrain the peak is given between brackets plus or minus the dispersion for that AFT age peak. The colour given to each point on the plot indicates the average of five Dpar measurements taken from that grain which is a measure for the apatite chemistry. The red-yellow colour bar below each plot shows the colour scheme that Dpar lengths can be obtained

by, given in micrometres. Length data is presented as histograms, lm is the average confined track length, n is the number of confined tracks identified and measured and σc is the standard deviation of confine track lengths..... 26
Figure 7: Time-Temperature models for samples 965, 967 and 972. These were constructed using the modelling software HeFTy (Ketcham 2005). Low-T thermochronological constraints for the models are shown as boxes with different colours representing the different low-T methods used in this study. The dashed constraint in the model for sample 972 was required to run the model and is not constrained by independent thermochronological data. Acceptable cooling path envelopes are shown in green, statistical good fit path envelopes are shown in blue. For sample 965 and 967 the default merit value for good paths of 0.5 and merit of value for acceptable paths of 0.05 was used. Models for these samples are based on AFT age and length data only and produce fairly simple cooling models. Sample 972 is based on a larger dataset including AHe data as well and consequently required a lower merit value for good fit paths of 0.2. Sample 972 exhibit a more complex thermal history. Those samples for which no length data could be obtained are not modelled. Sample 952 was not able to be modelled due to discrepancy between the track length histogram and the obtained AHe data for this sample..... 34
Figure 8: Cumulative radial plot of all AFT ages produced in this study demonstrating the AFT age peaks. Constructed using the software program RadialPlotter (Vermeesch 2009). For a description on radial plots see Figures 3 & 6. Five AFT age peaks are defined. ZHe and AHe age peaks are included as well. Grey zones highlight the cumulative age peaks of this study based on all low-T chronometers applied. 36
Figure 9: Digital elevation model with indication of previous AFT data obtained for the Gawler Craton (Gleadow et al. 2002, Kohn et al. 2002, Boone 2013). The locations of samples for this study are indicated by larger circles and colour code following their youngest AFT age peak. Modified from Boone (2013). The approximate location of the Garford and Kingoonya Palaeochannels are included. This demonstrates that sample 111 lies within the Garford Palaeochannel and provides a possible explanation for the anomalously young low-T ages yielded for this sample..... 42
Figure 10: Time-temperature plots showing all low-T thermochronometric data and proposed thermal history models for this study compared to the model presented by Weisheit et al. (2014). Later work includes low-T data from several studies in the northern Flinders Ranges area, east of the study region for this thesis (indicated on Figure 9). A stratigraphic graph of the major sedimentary formations within the study area is included. Formations that were deposited in exclusively marine environments including the Bulldog Shale were omitted as they are not a reliable indicator for exhumation. Within each plot, different low-T techniques are presented in different colours. For this study, the proposed cooling path is a best estimate for the entire study region. The cooling path is annotated to indicate which samples experienced the various thermal events. The lighter grey cooling path illustrates constrains the pre-Phanerozoic cooling that was observed for some samples. 43

Table 1: Adapted from Hand et al. (2007) detailing the major tectonothermal events to affect the Gawler Craton and their characteristics..... 9
Table 2: Major Phanerozoic tectonothermal events to affect southern Australia. 12
Table 3: Description of the major sedimentary formations to exist in this study area from. From (Drexel and Preiss 1995, Alexander and Hibburt 1996, (PIRSA) 2009, Geoscience-Australia 2014). 15
Table 4: Sample location, lithology, source and applied methods details. RO = rock outcrop, DC = drill core, AFT = Apatite Fission Track, AHe = U-Th-Sm/He, ZHe = U-Th-Sm/He 17
Table 5: AFT results for all samples in this study including confined track length data. Results of individual age peaks within samples are included. ρ_s is the surface density of spontaneous fission tracks (in 10^5 tracks/cm²). N_s is the number of counted spontaneous tracks, N is the number of successful grains analysed. ^{238}U is the average ^{238}U concentration, measured by LA-ICP-MS (in µg/g). Age (t) is given in Ma. For length data, l_m is the average confined track length, n is the number of confined tracks identified and measured and σc is the standard deviation of confined track lengths. 29
Table 6: Apatite (U-Th-Sm)/He and Zircon (U-Th-Sm)/He dating results. Aqt = Aliquot number. Concentrations for Th, U, Sm are in ppm. Concentrations for ^4He are in ncc/µg. Ft is the α-ejection correction factor (Farley 2002). AHe and ZHe ages (t) are given in Ma. Age peaks within each sample are given including the aliquot numbers (on which the ages are based on). 31