

***Towards a Geochronology for
Long-Term Landscape
Evolution, Northwestern New
South Wales***

Martin Lancaster Smith

March 2006

A thesis submitted for the degree of Doctor of Philosophy of The Australian
National University

This thesis is the result of my own work, unless indicated otherwise in the text.

Martin Lancaster Smith
March 2006
(October 2006 final submission)

Acknowledgements

To Professor Brad Pillans for invoking an interest in regolith geology and geochronology in a 2nd year geology undergraduate student on a summer research scholarship. Without that, who knows what I would have been doing? To the Cooperative Research Centre for Landscape, Environment and Minerals Exploration for providing a concentration of regolith research at the ANU, and for providing operating costs and a top-up scholarship to myself for the first 3 years and 3 months of the project. And to the Research School of Earth Sciences and the ANU for financial support for the duration of the project.

Many thanks must also go to my advisors. To Dr Ken McQueen and Dr Steve Hill for invaluable field supervision and discussion, to Dr Jim Dunlap and Dr Steve Eggins for greatly appreciated assistance in lab work and revisions of bits and pieces of this volume. Dr Graham Mortimer provided incalculable assistance with solution preparation and isotope geochemistry, your help went a lot further than you may think. Also to Dr Charlotte Allen for assistance with the laser ablation unit, and running the iron oxide solutions for U and Th analysis. Mike Shelley and Les Kinsley also provided much assistance with the laser ablation and multi-collector mass spectrometry. Dr Chris Klootwijk provided great assistance in analysis of palaeomagnetic data, and Dr Mart Idnurm a really good review of the palaeomagnetism chapter. Thanks also to Dr Andy Christie for initial discussions regarding silcrete formation and SEM analyses, and Dr Ulrike Troitzsch for guidance with XRD.

Thanks are also due to the Peak gold mines, CSA Mining, Troy Resources and Peak Hill Mine for access to Great Cobar, New Cobar, Chesney, CSA, McKinnons and Peak Hill Mines. Also to the UNSW Arid Zone Research Station, Fowlers Gap for access to the Sandstone Tank silcrete, and various other landholders for access to sites on their land.

There were many people who were great friends over the past four years, in particular, Aaron Lyman, Helen Bostock, Sarah O'Callaghan, Shaun Barker, Liz Forbes, Hugh Webb and Danielle Wright. There are many others, too numerous to name, whose friendship has sustained my time as a postgraduate student at ANU, and as a person in Canberra.

Finally, thanks are more than due (again) to my family. Mum provided invaluable proof reading of various drafts, and we will one day resolve the dash vs. hyphen debate...I think. Dad and my brother, Nick, have been there for me for support over the last four years as well. Yes, it's done.

Abstract

The study area extends from west of the Great Divide to the Broken Hill and Tibooburra regions of far western New South Wales, encompassing several important mining districts that not only include the famous Broken Hill lodes (Pb-Zn-Ag), but also Parkes (Cu-Au), Peak Hill (Au), Cobar (Cu-Au-Zn) and White Cliffs (opal). The area is generally semi-arid to arid undulating to flat terrain covered by sparse vegetation.

During the Cretaceous, an extensive sea retreated across vast plains, with rivers draining from the south and east. After the uplift of the Great Divide associated with opening of the Tasman Sea in the Late Cretaceous, drainage swung to the west, cutting across the Darling River Lineament. The Murray-Darling Basin depression developed as a depocentre during the Paleogene. Climates also underwent dramatic change during the Cenozoic, from warm-humid to cooler, more seasonal climates, to the arid conditions prevalent today. Up until now, there has been very little temporal constraint on the development of this landscape over this time period. This study seeks to address the timing of various weathering and landscape evolution events in northwestern New South Wales.

The application of various regolith dating methods was undertaken. Palaeomagnetic dating, clay $\delta^{18}\text{O}$ dating, (U+Th)/He and U-Pb dating were all investigated. Palaeomagnetic and clay dating methods have been well established in Australian regolith studies for the last 30 years. More recently, (U+Th)/He dating has been successfully trialled both overseas and in Australia. U-Pb dating of regolith materials has not been undertaken. Each method dates different regolith forming processes and materials. Palaeomagnetic and clay dating were both successfully carried out for sites across northwestern New South Wales, providing a multi-technique approach to resolving the timing of weathering events. Although (U+Th)/He dating was unsuccessful, there is scope for further refinement of the technique, and its application to regolith dating. U-Pb dating was also unsuccessfully applied to late-stage anatase, which is a cement in many Australian silcretes.

Results from this study indicate that the landscape evolution and weathering history of northwestern New South Wales dates back at least 60 million years, probably 100 million years, and perhaps even as far back as 180 million years. The results imply that northwestern New South Wales was continuously sub-aerially exposed for the last 100 Ma, indicating that marine sedimentation in the Murray-Darling and Eromanga-

Surat Basins was separated by this exposed region. The ages also provide further evidence for episodic deep chemical weathering under certain climatic conditions across the region, and add to the data from across Australia for similar events. In particular, the palaeomagnetic ages, which cluster at $\sim 60 \pm 10$ Ma and 15 ± 10 Ma, are recorded in other palaeomagnetic dating studies of Australian regolith. The clay ages are more continuous across the field area, but show older clays in the Eromanga Basin sediments at White Cliffs and Lightning Ridge, Eocene clays in the Cobar region, and Oligocene – Miocene clays in the Broken Hill region, indicating progressively younger clay formation from east to west across northwestern New South Wales, in broad agreement with previously published clay weathering ages from around Australia.

These weathering ages can be reconciled with reconstructions of Australian climates from previously published work, which show a cooling trend over the last 40 Ma, following an extended period of high mean annual temperatures in the Paleocene and Eocene. In conjunction with this cooling, total precipitation decreased, and rainfall became more seasonal. The weathering ages fall within periods of wetness (clay formation), the onset of seasonal climate (clay formation and palaeomagnetic weathering ages) and the initiation of aridity in the late Miocene (palaeomagnetic weathering ages).

This study provides initial weathering ages for northwestern New South Wales, and, a broad geochronology for the development of the landscape of the region. Building on the results of this study, there is much scope for further geochronological work in the region.

Table of Contents

Abstract	i
Table of Contents	iii
List of Figures	vi
List of Tables	x
1. Introduction	1
1.1 Aims of the thesis	1
1.2 Field area	2
1.3 Geology of the study area	4
1.3.1 Broken Hill Block	4
1.3.2 Cobar Basin	7
1.3.3 Eromanga-Surat Basin	8
1.3.4 Murray-Darling Basin	8
1.4 Modern climate and vegetation	10
1.4.1 Modern climates	10
1.4.2 Vegetation	12
2. Landscape Evolution and Cenozoic Climates	15
2.1 Landscape history	15
2.1.1 Carboniferous – Permian	15
2.1.2 Jurassic	16
2.1.3 Cretaceous	16
2.1.4 Late Cretaceous – Eocene	17
2.1.5 Oligocene – Recent	18
2.2 The history of the Canobolas Divide	19
2.3 Cenozoic climates of southeast Australia	22
3. Palaeomagnetic Dating	27
3.1 Development of the Mesozoic – Cenozoic Australian Apparent Wander Path (AAPWP)	28
3.2 Previous Work: Palaeomagnetic dating of the Australian regolith	32
3.3 Palaeomagnetic Samples, Northwestern NSW	39

Towards a Geochronology for Long-Term Landscape Evolution, Northwestern New
South Wales

3.3.1 Peak Hill Mine (32° 43' S, 148° 12' E)	39
3.3.2 Cobar samples	41
3.3.3 White Cliffs quarry samples (30° 30' S, 143° 00' E)	46
3.3.4 Broken Hill samples.....	46
3.4 Methods	49
3.5 Results.....	50
3.5.1 NRM and ChRM	50
3.5.2 Palaeomagnetic Poles and Ages	55
3.6 Discussion	60
3.7 Conclusion	64
4. $\delta^{18}\text{O}$ Dating of Clays	66
4.1 Samples.....	68
4.1.1 Cobar samples	68
4.1.2 Broken Hill and White Cliffs samples.....	70
4.2 Methods	72
4.3 XRD.....	75
4.3.1 Bulk rock XRD results.....	75
4.3.2 Clay fraction XRD results.....	75
4.4 $\delta^{18}\text{O}$ Results	76
4.5 Discussion.....	78
4.5.1 Clay $\delta^{18}\text{O}$ dating and other regolith ages.....	79
4.5.2 Clay $\delta^{18}\text{O}$ ages and palaeoclimates.....	80
4.6 Conclusion	82
5. (U+Th)/He measurements on Iron Oxides	83
5.1 Background.....	83
5.2 Samples.....	87
5.2.1 Northwestern NSW samples	87
5.2.2. South Australian and Western Australian samples.....	92
5.3 Methods	94
5.3.1 Thin sections and LA-ICP-MS.....	94
5.3.2 LA-ICP-MS results.....	95
5.3.3 Quantitative X-ray diffraction.....	97
5.4 (U+Th)/He dating of hematite.....	99

Towards a Geochronology for Long-Term Landscape Evolution, Northwestern New South Wales

5.4.1 Helium analysis methods	99
5.4.2 The Fe-oxy-hydroxide drift problem	100
5.4.3 U and Th analysis	101
5.5 (U+Th)/He dating results	102
5.5.1 Differential helium loss from different iron oxide phases	107
5.6 Discussion	111
6. Silcrete	115
6.1 Application of numerical dating techniques to silcrete	115
6.2 Sample descriptions	119
6.3 Scanning electron microscopy	122
6.4 LA-ICP-MS study	128
6.4.1 Methods	128
6.4.2 LA-ICP-MS transect results	129
6.4.3 LA-ICP-MS U-Pb dating	130
6.4.4 Discussion of LA-ICP-MS results	132
6.5 Multi-collector ICP-MS U-Pb and Pb-Pb solution analysis	132
6.5.1 Methodology	133
6.5.2 Results	134
6.5.3 Common lead correction of U-Pb data	139
6.6 Discussion	142
7. Conclusions	145
7.1 Palaeomagnetic and clay weathering ages	145
7.1.1 Comparison of weathering ages from this study	145
7.1.2 Comparison of weathering ages with landscape evolution models and climate	147
7.2 Episodic or continuous weathering?	150
7.3 Implications for mineral exploration	151
8. References	153

List of Figures

Figure 1.1. Northwestern New South Wales field localities (red dots)	2
Figure 1.2. White Cliffs locality map (pink indicates palaeomagnetic and (U+Th)/He sample, orange palaeomagnetic and clay samples).....	3
Figure 1.3. Cobar locality map (red: palaeomagnetic samples, blue: clays).....	4
Figure 1.4. Broken Hill locality map (all symbols as above, pink for ferricretes samples, grey for silcrete).....	5
Figure 1.5. Surface geology of northwestern NSW, after Liu <i>et al.</i> (2005).....	6
Figure 1.6. Mapped extent of the Eromanga-Surat Basin system and Murray-Darling Basin in NSW, with depth to the base of the Jurassic (Eromanga-Surat) and Cenozoic (Murray-Darling) sequences (compiled from Bembrick, 1975; Hawke <i>et al.</i> , 1975).....	9
Figure 1.7. Peak Hill climate averages.....	10
Figure 1.8. Cobar climate averages.....	11
Figure 1.9. Broken Hill climate averages.....	11
Figure 1.10. Climate averages for White Cliffs.....	12
Figure 1.11. Rainfall and maximum temperature averages across NSW (from www.bom.gov.au).....	13
Figure 2.1. Localities mentioned in section 2.2.....	20
Figure 2.2. Compilation of $\delta^{18}\text{O}$ data from Zachos <i>et al.</i> (2001).....	23
Figure 2.3. Reconstruction of the vegetation and climate from Eocene to Pleistocene for southeastern Australia (modified from Martin (1997), Figure 2).....	25
Figure 3.1. AAPWP from the Late Cretaceous through Cenozoic (McElhinny and Embleton, 1974; figure 6).....	28
Figure 3.2. Figure 1 (b) from Embleton and McElhinny (1982) showing the AAPWP as defined by digitally filtered poles derived from Cenozoic weathered profiles... ..	30
Figure 3.3. The revised Mesozoic – Cenozoic AAPWP (Idnurm, 1994; figure 6)	31
Figure 3.4. The AAPWP for the last ~260 Million years (Schmidt and Clark, 2000).....	32
Figure 3.5. Published data from palaeomagnetic studies of Australian regolith plotted on the AAPWP of Schmidt and Clark (2000).....	33

Figure 3.6. The McKinnons Pit regolith profile	38
Figure 3.7. Location map showing palaeomagnetic sample sites.....	40
Figure 3.8. The Peak Hill pit, showing nine sample sites... ..	42
Figure 3.9. Sample BAL002 from extensive mottling within the Ballast quarry site.....	43
Figure 3.10. Western wall of Ballast quarry showing mottling of steeply dipping Ballast beds	43
Figure 3.11. GCM004, typical sample from the Great Cobar Mine, representing ferruginous, weathered Great Cobar slate	44
Figure 3.12. East wall of the Chesney Open Pit.....	44
Figure 3.13. CRX002 from the well-cleaved, weathered Cobar Rail Cutting Site rocks	47
Figure 3.14. The Shearlegs road cutting in mottled Amphitheatre group sediments	45
Figure 3.15. Extensive mottling in the Carraweena pit.....	46
Figure 3.16. (left) White Cliffs Quarry cut into weathered Cretaceous sandstones... ..	48
Figure 3.17. (top) Sample WHC005 from the White Cliffs quarry, showing field orientation marks.....	49
Figure 3.18. Equal area plots of magnetic directions and intensity plots for representative samples from the Ballast quarry, Carraweena and Chesney sites (numbers correspond to demagnetisation steps).	52
Figure 3.19. Representative Byjerkerno ChRM directions, HT and HT1 components.....	53
Figure 3.20. Two component ChRM directions from the Cobar rail cutting, Great Cobar Mine, Peak Hill Mine, Shearlegs and White Cliffs sites (cont'd next page).	54 - 55
Figure 3.21. Equal area stereographic projection of mean declination and inclination data from all sites, including sites from Smith (2001).....	56
Figure 3.22. Palaeomagnetic results plotted on the AAPWP of Schmidt and Clark (2000)	60
Figure 3.23. Climate trends since the Paleocene... ..	63
Figure 4.1. Palaeolatitude of the Australian Continent since ~110 Ma based on Veevers (2001), figure 44.	67
Figure 4.2. Clay $\delta^{18}\text{O}$ composition of clays of various ages at various latitudes, after Bird and Chivas (1988a).....	68
Figure 4.3. The Rookery silcrete and underlying clay-rich weathering profile	69
Figure 4.4. Belah Trig silicified and weathered gravels.....	70
Figure 4.5. Teilta creek, showing dunes and weathered sediments (top).....	71
Figure 4.6. FGRC sample locality showing approximate sample site.	72

<hr/>	
Figure 4.7. Clay $\delta^{18}\text{O}$ compositions plotted against latitude and age (after Bird, 1988). Samples from this study and Bird (1988).....	78
Figure 5.1. (U+Th)/He sampling localities from eastern Australia... ..	88
Figure 5.2. (U+Th)/He sampling localities, Pilbara sample... ..	89
Figure 5.3. Scan of a polished thin section from the Kayrunnera iron oxide.....	90
Figure 5.4. Scans of polished thin sections of Wonaminta ferricrete... ..	91
Figure 5.5. The Back Tank ironstone.....	92
Figure 5.6. Scanned polished thin sections cut from Duff Creek samples.....	93
Figure 5.7. LA-ICP-MS transects across ferricretes... ..	96 - 98
Figure 5.8. Helium vs. uranium concentrations.....	105
Figure 5.9. Helium vs. thorium concentrations.....	106
Figure 5.10. Comparison of helium ages with palaeomagnetic, stratigraphic and host rock ages.....	114
Figure 6.1. Sandstone Tank silcrete with Eocene temperate rainforest flora... ..	118
Figure 6.2. Anatase geopetal capping on a quartzite clast from a silcrete in the Teilta area, NW NSW.....	118
Figure 6.3. Schematic section showing horizons and relative anatase abundance from Stuart Creek silcrete (top), with examples of Sandstone Tank features (top right; after Milnes and Thiry, 1991).....	120 - 121
Figure 6.4. Schematic diagram of a geopetal capping, showing sampling strategy for U- Pb solution MC-ICP-MS (Sandstone Tank sample).....	122
Figure 6.5. Plane polarised light photomicrograph of Farmcote windgap silcrete.....	123
Figure 6.6a. SEM image of silcrete cement.....	124
Figure 6.6b. Anatase-rich cement (pocked) and silica-rich cement (smooth).....	125
Figure 6.7. Late stage anatase cementing quartz/silica matrix in Teilta silcrete.....	126
Figure 6.8. Anatase replacement of a detrital grain in the Sandstone Tank silcrete.....	127
Figure 6.9. Laser ablation transect results for the Teilta geopetal capping.....	130
Figure 6.10. U-Pb concordia plot showing data from all Sandstone Tank LA-ICP-MS anatase spots (prepared using Isoplot).....	131
Figure 6.11. U-Pb concordia plot showing data from beige (non-iron oxide stained) Sandstone Tank LA-ICP-MS spots (prepared using Isoplot).....	131
Figure 6.12. U-Pb Tera-Wasserburg concordia plot showing data from all Sandstone Tank LA-ICP-MS anatase spots (prepared using Isoplot).....	132

Towards a Geochronology for Long-Term Landscape Evolution, Northwestern New
South Wales

Figure 6.13. ^{238}U - ^{206}Pb isochron diagram	136
Figure 6.14. ^{235}U - ^{207}Pb isochron diagram	136
Figure 6.15. Tera-Wasserburg plot of Sandstone Tank anatase data.....	137
Figure 6.16. Sandstone Tank silcrete anatase Pb isotope data plotted on a Stacey- Kramers (1975) ^{207}Pb - ^{206}Pb plot.	138
Figure 6.17. ^{208}Pb - ^{206}Pb plot of Sandstone Tank data, with Stacey-Kramers (1975) Pb growth curve.....	139
Figure 6.18. Tera-Wasserburg plot of common lead corrected data.....	140
Figure 6.19. Tera-Wasserburg plot of common lead corrected data from Sandstone Tank anatase, no outliers.	140
Figure 6.20. Iterative common lead corrected Sandstone Tank data.....	141
Figure 6.21. Outlier deleted, iterative common lead corrected Tera-Wasserburg U-Pb plot of Sandstone Tank anatase MC-ICP-MS data.	142
Figure 7.1. Map showing distribution of sites with palaeomagnetic weathering ages of ~100 Ma or more (red; see chapter 3 for discussion of significance of these results).....	146
Figure 7.2. Map showing sites with Paleocene clay ages and ~60 Ma palaeomagnetic weathering ages (red).	146
Figure 7.3. Map showing distribution of sites with Oligocene – Miocene weathering ages (red)	147
Figure 7.4. Comparison of clay and palaeomagnetic ages with climatic data (from Martin, 1998) for southeastern Australia for the past 45 million years	150

List of Tables

Table 3.1. Published palaeomagnetic data from Australian regolith dating studies.....	34
Table 3.2. Palaeomagnetic results from pilot NW NSW samples.....	57
Table 3.3. AAPWP reference poles (from Schmidt and Clark (2000)).....	58
Table 4.1. Sample descriptions and XRD results.....	76
Table 4.2. Clay $\delta^{18}\text{O}$ results.....	77
Table 5.1. Results of SIROQuant and XRD analysis.....	98
Table 5.2. Helium data for all iron oxides measured. Greyed out rows indicate samples where gas was pumped away.....	103
Table 5.3. Uranium and thorium data for iron oxides analysed for He.....	104
Table 5.4. (U+Th)/He ages for iron oxides from northwestern New South Wales... ..	107
Table 5.5. Iron Oxide diffusion corrected helium and resulting ages.....	108
Table 5.6. Goethite corrected helium and resultant ages.....	109
Table 5.7. Comparison of raw and corrected (U+Th)/He ages.....	110
Table 6.1. Chemistry of various morphologies from SEM of the SST silcrete sample, all results reported as Wt% oxide.....	127 - 128
Table 6.2. Uncorrected lead data.....	135
Table 6.3. Uranium data for solution MC-ICP-MS.....	134
Table 6.4. Uncorrected uranium-lead ratios.....	135
Table 6.5. Common lead corrected ratios.....	139
Table 6.6. Iterative common lead corrected ratios.....	141